USAAMRDL-TR- 75-53

HELICOPTER RELIABILITY GROWTH EVALUATION

12

Bell Helicopter Company
Reliability Engineering
P. O. Box 482
Fort Worth, Tex. 76101

D54200

April 1976

Final Report

Approved for public release;
distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

The issue of helicopter reliability growth during development has been a major area of concern within the Army R&D community for several years. The findings presented in this report represent a significant step toward gaining a much improved insight into reliability growth rate and the factors that control it. Attention is specifically directed to the findings pertaining to the rather small growth which one should expect during the development phase; this directly contradicts previously established positions that substantial reliability growth during the early portion of the developmental phase was achievable. The contractor's position that lead time for corrective actions prohibits any significant growth during the development phase is well founded and considered to be fully acceptable. The findings presented in the report are recommended for direct use in new helicopter system development program test planning. However, this Directorate believes that the subject of reliability growth for helicopters will never lend itself to exact quantification; consequently, the reader should examine in detail all assumptions provided in the report prior to direct use of the program results.

Thomas L. House of the Military Operations Technology Division served as Project Engineer for this effort.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(19) REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (18) USAAMRDL-TR-75-53	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) HELICOPTER RELIABILITY GROWTH EVALUATION,		5. TYPE OF REPORT & PERIOD COVERED Final Report,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) G. S. Conway (12) 170p. (15)		8. CONTRACT OR GRANT NUMBER(s) DAAJ02-73-C-0097 New
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bell Helicopter ~~Company~~, Reliability Engineering, P. O. Box 482, Fort Worth, Texas 76101		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63204A 1F163204DB38 00 018 EK
11. CONTROLLING OFFICE NAME AND ADDRESS Eustis Directorate U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia 23604		12. REPORT DATE (11) Apr[redacted]76
		13. NUMBER OF PAGES 169
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) DA-1-F-163204-DB-38		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(17) 1-F-163204-DB-3800

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mean Time Between Failures (MTBF)
Off-board MTBF
Reliability Planning
Reliability Program Management
Design Lead Times
Helicopter Hardware Lead Times
Helicopter Test Requirements
Helicopter Test Time
Test Program Requirements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results and data resulting from a research evaluation made of the reliability growth characteristics of the development and early production of UH-1D and AH-1G helicopters. The major subjects covered by the technique and backed by research are: off-board MTBF, reliability (MTBF) growth versus test time, and reliability growth versus calendar — over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

054 200 mt

Block 19

Mean Time Between Maintenance Actions
Helicopter Reliability
Helicopter Reliability Growth
M&R Field Programs

Block 20

time. A tentative technique for predicting helicopter reliability growth applicable to reliability program planning and management is also presented based on the results of the research. An example of the technique procedures applied to a hypothetical helicopter is also presented.

PREFACE

This report provides a historical reliability growth assessment for the UH-1D and AH-1G helicopters and a reliability growth prediction technique for helicopters. The analysis was conducted under Contract DAAJ02-73-C-0097 for the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia, with technical direction provided by Messers. T. L. House and V. W. Welner.

The author wishes to express appreciation for the technical assistance of Messrs. J. A. Gean, Chief of Reliability, Maintenance Technology, and System Safety, Bell Helicopter Company, and G. E. Knudsen, Group Engineer for Reliability, Bell Helicopter Company. Their efforts made a significant contribution to the performance of this program.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

TABLE OF CONTENTS - Concluded

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Continued

LIST OF ILLUSTRATIONS - Concluded

LIST OF TABLES

LIST OF TABLES - Concluded

1.0 INTRODUCTION

The prediction and measurement of reliability growth during the development of new systems has become a major issue in the Department of Defense. The program planning requirements for UTTAS (Utility Tactical Transport Aircraft System) and AAH (Advanced Attack Helicopter) dictate that reliability milestones be established and the development test effort be tailored to achieve the projected reliability growth for the new systems. It has become apparent that the only reasonable way to derive expected reliability growth rates is to perform an in-depth analysis of previously developed similar systems. Helicopter reliability growth histories can be explored, and from extrapolation of the data a prediction technique may be formed. Although certain work has been conducted to understand reliability growth for helicopter major dynamic components (transmission, rotor heads, etc.), an analysis of system level growth has not been accomplished.

There is currently a prediction technique, the RPM (Reliability Planning and Management) method,[1] that works quite well for complex electronic equipment. It is statistically sound and easy to apply. Because of this, it is tempting to apply it to systems that it does not fit. Further, it requires an exercise in engineering judgment in selecting values for its parameters. Small errors in selecting these values can cause large errors in test time requirements. In addition, there has not been a study to substantiate its use for helicopters.

The goals of this study were to evaluate the reliability growth histories of three helicopters, the UH-1D, the AH-1G, and the OH-58A, and to determine growth characteristics and parameters that may be applicable to future aircraft development. Early in the analysis it was found that the data required to support an analysis of the OH-58A reliability growth was not available. This aircraft was dropped and the study was centered around the UH-1D and AH-1G. An account of the factors leading to termination of the OH-58A analysis is presented in Appendix A. The UH-1D and AH-1G growth histories were evaluated to determine if they are typical of the RPM technique. If they are not typical, then a basis for a

---

[1]Miller, S. G., and Selby, J. D., Reliability Planning and Management (RPM), The General Electric Company, Utica, New York, September 26, 1970.

viable prediction technique must be developed. The UH-1D and AH-1G are, respectively, utility and attack helicopters which have been produced and used in large quantities for sufficient flight hours to make their use feasible in such an evaluation. Further, under the M&R program,[2,3,4] a controlled sample of helicopters from each UH-1D and AH-1G fleet was monitored for failure and unscheduled maintenance actions. These data were subsequently used to introduce design changes. These in turn led to the reliability growth experienced by these two aircraft. The data from the M&R program were used in this study to determine the rate of reliability growth and to determine the growth characteristics of the UH-1D and AH-1G.

In addition to the M&R program, there were other data sources investigated in support of this study. Several analyses were conducted, but did not further this study. Appendix A presents these sources with the various reasons for their rejection.

The Mean-Time-Between-Removals (MTBR) parameter and its relationship to subsystem level reliability growth was investigated. However, it was found that the data were not in a form that would allow the required information to be extracted in a cost-effective manner. Budget and time considerations dictated that this part of the study be abandoned.

As the study progressed, it became apparent that many factors influenced reliability growth and had to be examined. It also became obvious that the time and funds available limited the depth of examination of all factors and required careful direction of the effort in order to accomplish the most with the funds available.

---

[2]Contract AF 33-657-11111, UH-1 Maintainability and Reliability (M&R) Program, May 1965 through January 1966.

[3]Contract DA23-204-AMC-03694(T), UH-1 M&R Program, January 1966 through April 1967.

[4]Contract DAAJ01-67-C-1588(G), UH-1/AH-1 M&R Program, April 1967 through June 1970.

Some of the factors affecting reliability growth are:

- rate of test time accumulation
- rate of failure mode identification
- rate of problem corrective action initiation
- cost of corrective action
- time lag between initiation of corrective action and the incorporation of redesigned hardware on the helicopter
- program intensity

These and other factors were examined for their individual impact on reliability growth.

2.0 APPROACH

2.1 BASIC CONSIDERATIONS

In the past, references to reliability growth have been associated with development programs for new equipment. For that reason, the original intent of this contract was to closely examine bench test records, quality conformance tests, and flight test records. It was planned that data could then be extracted from them that would allow reliability growth tracking during their development period. In examining these records, it became obvious early in the program that the required information was not available in any form that would allow reliability growth to be tracked against test hours. Further, none of the three aircraft had formal reliability programs during development. However, the UH-1D and the AH-1G were subjects of an M&R program during their early production years. It is reasonable to assume that the periods of R&M monitoring are the development phases of these aircraft since a concerted effort was being made to eliminate specific failure modes under a controlled program. A 2400-flight hour reliability and maintainability demonstration was the only test program conducted on the OH-58A production aircraft. Only two aircraft of the same fiscal year model were used. Although current reliability was tracked, reliability growth was not. The data were not used specifically for eliminating failure modes. Design changes were made based on the data; however, this did not constitute a development program. Therefore, no attempt was made to use the data for reliability growth study purposes.

Subsystems not required for flight by the basic helicopter were not considered in this study. This was done to eliminate hardware not common to the UH-1D and the AH-1G, and to keep the subject of the study centered around the air vehicle. For these reasons, communications and navigation avionics and weapons subsystems equipment were not considered in the aircraft failure rates.

The goals of this study were accomplished by the following tasks, discussed in chronological order. The UH-1D and AH-1G reliability growth histories were examined and significant characteristics discussed. The growth histories were then compared to each other, establishing those points where they are alike and where they differ. Included is a discussion of the various stimuli that influenced the reliability growth rates of the helicopters and the effect that each may have had. Next, the parameters of the RPM technique for reliability growth prediction were applied to the growth histories of the two aircraft. A limited prediction technique was then developed based on the reliability growth experiences of the UH-1D and AH-1G.

2.2 APPROACH TO RELIABILITY GROWTH ASSESSMENT OF UH-1D AND AH-1G HELICOPTERS

2.2.1 Factors That Led to Use of M&R Program Data

Reliability growth of UH-1D and AH-1G helicopters was attained by detecting and defining existing and potential problems and by initiating and incorporating corrective action. The UH-1/AH-1 M&R Program provided the only documented history of such events including, in most cases, verification of problem correction. Accountability required for individual failures, time bases, and corrective actions provided the foundation for the reliability growth assessment presented in this report. The M&R data supplied further information on component/system description, failure modes, problem analysis, recommendations and status. The M&R Program for both the UH-1D and the AH-1G based its activities on failure monitoring of delivered production aircraft in their real-life environment. Reliability growth is evaluated by measurement of those incremental failure rate improvements induced by each corrective action incorporated on subsequently manufactured aircraft.

2.2.2 Discussion of UH-1D/AH-1G Helicopters Monitored by the M&R Program

Neither the UH-1D nor the AH-1G had formal reliability programs during their design phases. Thus, the M&R program had no development program impact on these aircraft. This and the shortcomings of other sources investigated (see Appendix A) have precluded attempts to make a historical reliability growth assessment for these helicopters during the period between program inception and first flight. This study investigated reliability growth beginning with initial aircraft deliveries.

M&R program data covered more fiscal year (FY) configurations for the UH-1D than it did for the AH-1G. In the course of the program, begun in June 1964, five fiscal year configurations of the UH-1D were monitored. The data include FY62 through FY66 aircraft, with monitoring ending August 1967. Records of corrective action production effectivity permitted reliability growth to be calculated through the FY69 production UH-1D. AH-1G failure monitoring began in June 1967 and ended with program termination in October 1969. Included were data samples from FY66, FY67, and FY68 aircraft. Corrective action effectivities permitted reliability growth to be calculated through the FY70 production AH-1G. Reliability growth for eight FY production models of the UH-1D is compared to that for five of the AH-1G.

Reliability growth of the UH-1D and AH-1G resulted mostly from design changes initiated to eliminate specific failure modes. Tables 1 and 2 summarize those changes that were made to each new UH-1D and AH-1G fiscal year model, respectively, that made it a unique configuration with a corresponding unique MTBF. Nonhardware changes included procedural changes and technical manual changes.

2.2.3 M&R Indexed Problems Used in the Analysis

The M&R Program Monthly Progress Report[5] was used to establish the causes for reliability growth and operating or test time required to identify the problems and validate their corrective action. Information used to establish the facts and chronology of these events was found in problem narratives of the monthly progress report. These problems were assigned an index number when they were initially researched. In general, seven occurrences of a failure mode were considered to justify an investigation to determine whether a problem truly existed. However, safety-of-flight failure modes were considered to be identified problems the first time they occurred. Numbers 1 through 133 are UH-1D related problems. Numbers 601 through 883 are AH-1G related problems.

Tables 3 and 4 present summaries of the UH-1D and AH-1G problems addressed in the progress report. They show equipment failure rates (where corrective action was accomplished) prior to corrective action (λ_o) and subsequent to corrective action (λ_1). Notes and comments provide details on individual problem disposition at the end of the M&R program.

Of the 133 UH-1D problems identified:

- 61 had corrective action.
- 30 were avionics, navigation, or weapons subsystem equipment failures and thus were not applicable to this project.

---

[5]Fox, R. G., UH-1, AH-1G Maintainability and Reliability Program (M&R) Monthly Progress Report, Report Number 205-099-157, Revision AW, Bell Helicopter Company, Fort Worth, Texas 76101, June 30, 1970.

- 8 were not considered to be significant at the time and were closed without corrective action.

- 2 were "lived with" as no feasible solution exists.

- 17 had corrective actions proposed which were pending when the UH-1D portion of the M&R program ended.

- 15 had corrective actions recommended which were rejected by the customer.

Rejections were usually based on the lack of cost effectiveness, lead time problems, and other factors recorded in the minutes of the M&R program monthly meetings.

Of the 283 AH-1G problems identified:

- 92 had corrective action.

- 88 were avionics, navigation, or weapons subsystem equipment failure and thus were not applicable to this project.

- 22 were not considered to be significant and were dropped without corrective action.

- 1 was "lived with" as no feasible solution exists.

- 77 either had solutions pending or had investigations still in progress when the M&R program was terminated.

- 3 had corrective action rejected by the customer.

2.2.4 Procedure Used To Analyze the M&R Program Data

The same technique was used to assess reliability growth for both the UH-1D and the AH-1G. In general, the analysis is based on measurement of the change of aircraft failure rate resulting from corrective action. The corrective actions in the form of altered designs, deletion of parts, substitution of parts, configuration changes, procedural changes, etc., were inititated to alleviate specific failure modes with known failure rates. By subtracting from the total aircraft failure rate the amount by which corrective action decreased these known failure rates, reliability growth was established. This was accomplished in the following steps:

- Monitored flight hour values were determined from computer listings of monitored aircraft. An example of these listings is presented in Figure 1.

- The components that experienced a reliability improvement were determined from problem narratives in the 205-099-157 UH-1, AH-1G M&R Monthly Progress Report. An example of these narratives is presented in Figure 2.

- Failure rates prior to corrective action (λ_o) and following corrective action (λ_1) and the effectivity dates of the corrective action were established for those of components that experienced a reliability improvement. The problem narratives provided the effectivity of the problem corrective actions. The failure rates, λ_o and λ_1, were determined from failure counts and time bases. The $MTBF_o$ values were computed by dividing the number of failures experienced by a component prior to receiving corrective action into the number of flight hours accumulated prior to the effectivity date of the corrective action. Taking the reciprocal of that MTBF provided the failure rate, λ_o. The $MTBF_1$ values were computed by dividing the number of failures experienced by a component after receiving corrective action into the accumulated flight time following the effectivity date of the corrective action. Examples of the data listings from which the failure counts were made are presented in Figures 3 and 4. Note that many of the corrected problems exhibited a residual failure rate of zero, i.e., $\lambda_1 = 0$. This occurred due to either of two reasons; the problem component was eliminated from the helicopter or the redesigned component experienced no failures during the subsequent monitoring period.

- A baseline failure rate was computed from failures of those components that did not experience a reliability improvement, i.e., received no design change. This was accomplished by counting those failures and dividing that number into the total aircraft time base for a baseline MTBF. The reciprocal is the baseline failure rate. Tables 5 and 6 are baseline failure rate summaries for the UH-1D and AH-1G, respectively. Failure counts are shown that permitted a baseline failure rate to be calculated for each subsystem. The sum of the subsystem baseline failure rates is the total aircraft baseline failure rate.

- By grouping λ_o's and λ_1's of the corrected problems by the fiscal year effectivity of their correction and summing those rates for each fiscal year with the baseline failure, the total aircraft failure rate is computed for each fiscal year. Figure 5 illustrates this procedure. Tables 7 and 8 and Figures 6 and 7 present the UH-1D and AH-1G growth summaries.

Note that these plots show the MTBF attained by each FY helicopter at the time of its entry into service. The 7.8-hour off-board value for the YUH-1D is the off-board MTBF as defined by the Army 1000-hour Logistical Evaluation.[6] The 6.6-hour value for lots 4 and 5 FY 66 AH-1G's is the off-board MTFB established by early CONUS monitoring of the AH-1G prior to delivery of the AH-1G to Vietnam.

Note in Tables 5 and 6 the flight hour values used in computing the baseline failure rates. The total M&R program flight time was 49,947 hours for the UH-1D. However, the UH-1D baseline failure rate is computed from a time base of 24,824 flight hours. Early in the UH-1D analysis portion of this study it was believed that the accuracy of the M&R program data could be increased by selecting only certain aircraft for use in the analysis. The selection criteria were designed to:

- eliminate infant mortality failures,
- provide data from aircraft with a continuous monitoring history,
- omit those aircraft where evidence of incomplete failure reporting existed, and
- reduce the influence of the first component overhauls.

These criteria resulted in 26 UH-1D aircraft being selected whose total M&R flight time was 24,824 hours. Selection of these aircraft was tedious and time consuming. The UH-1D analysis using those 26 aircraft was performed, with the results being presented in this study. Prior to the start of the AH-1G work, a sensitivity analysis was conducted to determine what differences in outcome, if any, resulted from

[6] U. S. Army Transportation Aircraft and Support Activity, 1000-Hour Logistical Evaluation - YUH-1D, Fort Rucker, Alabama, 1962.

using selected aircraft versus all of the monitored aircraft. No differences were found to exist. Therefore, the AH-1G analyses were conducted using all of the monitored aircraft. Since there was nothing to be gained by reworking the UH-1D analyses using all of the monitored UH-1D aircraft and since the cost of rework was high, the analysis was left in its current form.

2.2.5 Cautions Discussed for Programs With Similar Goals

The intent of the M&R programs was to identify and correct problems. In accomplishing this, the UH-1D and AH-1G aircraft experienced significant reliability growth. It is not unreasonable to review the approach of the M&R program and compare that to another program designed to accomplish similar goals. The Eustis/Boeing approach[7] deserves particular attention. Its logic is that:

- If one generally knows the modes of failure that will occur on components of a newly designed helicopter, reliability tests run for a period twice the MTBF of a particular failure mode will have an 87 percent probability of exposing that mode, thus permitting its correction. Further, if the requirement is to expose as many failure modes as possible equal to or less than a given MTBF, testing can be conducted for a period twice the given MTBF value, then 87 percent of those failure modes with an MTBF equal to the given MTBF value will be exposed. For those failure modes with MTBF's less than the given value, greater than 87 percent will be exposed.

Note that most of the helicopter failure modes listed as identified and corrected in Tables 3 and 4 have an MTBF equal to or less than 5,000 hours. Using the Eustis/Boeing approach it might be logical to assume that a 10,000 test period spread over several prototype vehicles could have yielded close to the same results obtained on the UH-1D and AH-1G M&R programs where monitored flight hours were 50,000 and 66,000 hours,

[7]Rummel, K. G., "Helicopter Development Reliability Test Requirements," USAAMRDL Technical Report 71-18, from the Boeing Company, Vertol Division, Philidelphia, Pennsylvania, to Eustis Directorate, USAAMRDL, Fort Eustis, Virginia, April 1971.

respectively. However, in making that assumption important factors evident in the M&R programs may be easily overlooked:

- Many failure modes are calendar time dependent. Thus, a relatively short calendar period test program may not reveal these failure modes, even though the test hours are adequate.

- A significant number of failure modes are environment dependent and will not be exposed in a test program on prototype aircraft. The M&R programs were conducted on fielded initial production aircraft in their actual combat environment. Testing in a sterile environment will expose only those failure modes that are inherent to the hardware.

- Corrective actions initiated for failure modes identified during a short duration prototype test program will most likely not be incorporated until the first production aircraft is produced. Thus, the effectiveness of a corrective action will not be evaluated while the test is still in progress. In turn, reliability growth cannot be fully evaluated. This is not to say that reliability growth cannot be evaluated while testing is in progress. However, to do so, a pattern of "test-fail-stop test-incorporate design fix - test to verify" would be required. Since design changes to helicopters require long lead times, following such a pattern would be unrealistic. Equipment and personnel would remain idle for long periods and the length of the program would be prohibitive.

- A large amount of test time is required to ensure sufficient exposure of failure modes for problem identification. In general, seven occurrences of a failure mode in the M&R program were considered to justify investigation to determine whether a problem truly existed. With 95 percent confidence, a particular failure mode could be expected to be seen on between 10 and 43 percent of the fleet when it was observed 7 times on the monitored sample of 40 aircraft. Monitoring a small group of prototype aircraft will not provide a statistical base for projecting fleet problems based on the sample.

TABLE 1. UH-1D CONFIGURATION CHANGES DURING MONITORING PROGRAM

Fiscal Year Aircraft	Configuration Changes
FY62	Basic configuration
FY63	Tail rotor sprocket cover redesigned.
FY64	Cargo door stop redesigned for increased strength.
	Redesigned compartment door latches installed.
	Shoulder harness inertia reel and manual control repositioned.
	42-degree gearbox input quill Buna-N seal replaced with silicone rubber seal.
	Mesh screen wire added to fuel pump outlet fitting.
FY65	Cargo hook hole bumper removed from airframe. Redesigned bumper added to hook.
	Doublers added to outside skin panels in tail-boom.
	Self-locking feature added to Rivnuts on skid gear attach bolts.
	Doublers added to upper and lower engine air induction baffle.
	Landing gear cross-tube strap increased in width.
	Stiffener added to lower engine panel assembly.
	Hydraulic inspection panel redesigned without transparent window.
	Crimp added to tail-boom fin access door hinge.

TABLE 1. (Cont'd)

Fiscal Year Aircraft	Configuration Changes
FY65 (Cont'd)	Transmission mount damper redesigned and wave washer added.
	Stitching modified for troop seats.
	Protective covers added to pilot/copilot seat assemblies.
	Reconfigured gravity feed hydraulic system added.
	Steel sleeve added between outer bearing surface and scissor lever bore.
	Redesigned main rotor pitch link rod-end bearing added.
	Tail rotor hydraulic boost cylinder piston rod size decreased.
	Teflon fabric bearing added to synchronized elevator forward bellcrank.
	Improved bearing installed, synchronized elevator control idler.
	Main rotor blade leading-edge material changed to improve erosion characteristics.
	Pitch-horn bolt reversed.
FY66	Engine barrier filter added.
	Redesigned clamping installed for transmission oil hoses.
	Threaded oil plub replaced snap-in plug in transmission.
	Swash-plate ring assembly horn redesigned for increased strength.
	Transmission fairing seal redesigned with additional retainers.

TABLE 1. (Cont'd)

Fiscal Year Aircraft	Configuration Changes
FY66 (Cont'd)	Engine air inlet filter seal redesigned with improved retainers.
	Transmission left beam assembly redesigned for increased tensile strength.
FY67	Vibration dampers added between air inlet screen and oil cooler blower housing.
	Tail rotor drive shaft hanger bearing replaced with redesigned bearing.
	Engine-to-transmission drive shaft redesigned to include elastomeric boot assembly and improved couplings.
	Swash-plate locking washers changed to prevent cupping.
	Stabilizer bar lever bearing increased in size.
	Door jettison pins material changed to stainless steel.
	Self-locking feature added to tail rotor control tube nut.
	Improved retainers added to transmission cowl seals.
FY68	Oil-resistant feature added to bulkhead door seals.
	Cargo door rollers redesigned to be less susceptible to abrasion.
	Kacarb bearings added to tail rotor pitch change link assembly.
	Forward roof window changed from Plexiglas to polycarbonate.
	Main rotor hub seal redesigned to include an elastomer seal.

TABLE 1. (Concluded)

Fiscal Year Aircraft	Configuration Changes
FY68 (Cont'd)	Tail rotor blade leading-edge material changed to improve erosion characteristics.
	Starter/generator cooling fan eliminated from design.
	Roof access steps added.
	Main transmission input quill assembly redesigned with improved oil seals.
FY69	Windows in hinged cargo doors eliminated.
	Particle separator redesigned to include improved fasteners.
	RPM warning box redesigned.
	Hydraulic boost cylinders redesigned for improved piston-rod gland sealing.

TABLE 2. AH-1G CONFIGURATION CHANGES DURING MONITORING PROGRAM

Fiscal Year Aircraft	Configuration Changes
FY66	Basic configuration
FY67	Redesigned float switch support for engine oil system.
	Main rotor pitch link bearing redesigned.
	Mast spinner eliminated from design.
	Main rotor blade tiedown hook shortened.
	Doublers added to skid tubes at cross-tube attach point.
	Ammunition compartment door rub strip riveted in lieu of bond to door assembly.
	Engine oil cooler configuration changed to bleed air driven fan.
	Gunner and pilot steps changed to one-piece assemblies.
	Main rotor friction collet fingers increased in thickness.
	Battery cable quick-disconnect redesigned.
	Cowl door sealing strips eliminated.
	Skid tube attach bolts lengthened.
FY68	Tail lights relocated at base of tail fin.
	Tail pipe redesigned with improved mounting provisions.
	DC voltage regulator improved.
	Canopy seals redesigned.

TABLE 2. (Cont'd)

Fiscal Year Aircraft	Configuration Changes
FY68 (Cont'd)	Step added to aft side of cross tube.
	Improved bearings added to tail rotor pitch change links.
	Clamping arrangement for transmission oil lines improved.
	Stability Control Augmentation System (SCAS) redesigned to eliminate electromagentic interference.
	Rigid oil cooling lines changed to flexible lines.
	Oil cooler blower mount strengthened.
	Proseal added to clevis pin holes in cable pulleys.
	High-capacity rotary inverter provided.
	High-capacity static inverter provided.
	Main rotor trunnion attach bolts with increased tensile strength provided.
	Tail pipe ejector redesigned to eliminate cracking.
	Improved lockout valve provided for hydraulic system.
	Improved ventilation ducts provided.
	Cutout forward of gunner collective boot elongated.
	Improved pilot seat adjustment lever provided.
	Improved engine mount support bearing provided.
	SCAS amplifier yaw channel modified.

TABLE 2. (Cont'd)

Fiscal Year Aircraft	Configuration Changes
FY68 (Cont'd)	Strip type ground added to navigation lights in lieu of wire type.
	Cross-tube cap assembly rubber pad bonding improved.
	Cabin air elbow duct reinforced.
	Steel elbows used in hydraulic system in lieu of aluminum.
	Clamping arrangement for hydraulic lines improved.
	Air inlet screen actuator hermetically sealed.
	Landing light eliminated.
	Cross-tube step assembly strengthened.
	Engine oil pressure warning switch replaced with improved switch.
FY69	Improved tail rotor configuration provided.
	Improved SCAS transducer configuration provided.
	Improved canopy locks provided.
	Main transmission input quill assembly redesigned.
	Coated tail rotor control cables provided in lieu of noncoated cables.
	Improved RPM warning box provided.
	Bonding method improved for main rotor blade leading-edge erosion strips.
	Main rotor pitch change link redesigned.
	Improved main rotor blade provided.

TABLE 2. (Concluded)

Fiscal Year Aircraft	Configuration Changes
FY69 (Cont'd)	Wall thickness increased on skid tubes.
	42-degree gearbox cover material changed to aluminum.
	Rubber shock mount added to engine fuel pressure transmitter.
	Transmission lift link redesigned.
	Clamping revised for generator cooling air hose.
	Improved particle separator provided.
	Tail rotor drive shaft cover redesigned.
	Transmission manifold-to-filter rigid oil line replaced with flexible oil line.
	Transmission fifth mount support redesigned.
	Transmission oil pressure warning switch replaced with improved switch.
	Self-locking screws incorporated into pilot's canopy latch installation.
FY70	Improved door handles incorporated on gunner's canopy.
	Crew compartment vent fan redesigned.
	Friction collet redesigned.
	Engine tripod rod-end bearings replaced with improved bearing.
	Lateral cyclic control magnetic brake redesigned.

TABLE 3. UH-1D M&R PROBLEM SUMMARY

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Seal deteriorated/separated on island structure/access doors	001	840	0	1	Redesigned seal incorporated on FY64 & sub aircraft
Windshield scratched by wiper blades	002	-	-	2	No corrective action
Insufficient drain holes in fuselage	003	-	-	3	No corrective action
Lower aft fuselage stiffener cracking	004	-	-	4	Analysis not continued
Cargo hook hole bumper loose/deteriorating	005	1215	0	1	Redesigned bumper incorporated on FY66 & sub aircraft
Cargo door stop breaking	006	2380	56	1	Redesigned stop incorporated on FY66 & sub aircraft
Cargo door roller/slider failure	007	1980	461	1,5	New part for FY64 & sub, procedure change 9/68
Landing gear cap assembly bumper loosening	008	3081	339	1	Redesigned part incorporated on FY64 & sub aircraft
Compartment door latches broken	009	1168	0	1	Redesigned parts incorporated effective 9/64

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Tail-boom fin cracking at Station 423	010	420	0	1	Installation redesign incorporated FY64 & sub aircraft
Landing gear skid shoe bolt missing	011	140	0	1	Redesigned parts incorporated on FY64 & sub aircraft
Tail rotor cables wearing at pulley or grommet	012	-	-	6	No corrective action
Rotating (anticollision) light bulb burnout	013	-	-	3	No corrective action
Navigation tail light bulb malfunctions	014	-	-	3	No corrective action
FM radio set inoperative (AN/ARC 44)	015	-	-	7	Not applicable
J-2 compass gyro set malfunctions	016	-	-	7	Not applicable
Troop seats tearing at seams	017	1898	0	1	Improved seats incorporated on FY65 & sub aircraft
Glare shield panel cracking	018	-	-	7	Not applicable
Blackout and soundproofing attach strip bond failure	019	-	-	7	Not applicable

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Soundproofing blankets torn by troop equipment	020	-	-	7	Not applicable
Cargo hook malfunctions	021	-	-	7	Not applicable
Hydraulic boost servos leak/ cylinder components worn	022	2819	0	1	Redesigned parts incorporated on FY68 & sub aircraft
Hydraulic reservoir leaking and boot deteriorated	023	1280	0	1	Redesigned parts incorporated on FY65 & sub aircraft
Engine air induction baffle cracking	024	2555	0	1	Redesigned installation incorporated on FY64 & sub aircraft
Oil cooler installation components cracked/broken	025	2909	141	1	Redesigned parts incorporated on FY65 & sub aircraft
Engine compressor blade erosion	026	-	-	8	Configuration change incorporated on FY65 & sub aircraft
Stabilizer bar damper link tube rod end bearings worn	027	-	-	2	No corrective action
AN201KP8A bearing loose in scissors lever	028	1140	0	1	Redesigned parts incorporated on FY64 & sub aircraft

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Main rotor pitch link rod end bearing (-119-1) worn	029	1076	0	9	Change effective 7/65
Tail rotor pitch change link bearings worn	030	1611	0	1,9	Change effective 10/68
Rotating controls and rotor components corroded	031	2054	0	5	Change effective 11/67
Main rotor hub seal leak at grips	032	523	0	1	Change effective 8/68
Main rotor and tail rotor blade leading-edge erosion	033	1472	627	1	Redesigned blades incorporated on FY65 & sub aircraft
Main rotor pitch horn damaged (bolt and cotter pin rotated)	034	280	0	5	Change effective 1/66
Tail rotor drive shaft hanger bearing failure	035	2239	217	1	Redesigned parts incorporated on FY66 & sub aircraft
Transmission drain system clogged with sand	036	-	-	3	No corrective action
Engine-to-transmission drive shaft coupling failure and seal leak	037	765	0	1,5	Effectivity FY67 & sub, TM Change 6/67

TABLE 3. (Continued)

Problem	M&R index no.	λ_o x 10	λ_1 x 10	Notes	Comments
Transmission oil hoses rub case and/or clamp; case worn	038	2049	1727	1	New parts added on FY64 & sub aircraft
Tail rotor hydraulic boost cylinder leaking	039	1333	1200	9	Change effective 9/65
Landing gear cross-tube strap rivets shearing	040	187	0	1	Redesigned parts incorporated on FY65 & sub aircraft
Ground handling gear malfunctions	041	-	-	7	Not applicable. Problem not associated with flight hardware.
Main and spare inverter failures	042	-	-	4	Analysis not continued
AN/ARC-51X UHF receiver/transmitter inoperative	043	-	-	7	Not applicable
ADF receiver inoperative (AN/ARN-59)	044	-	-	7	Not applicable
Engine starter-generator cooling fan failure	045	170	0	8	Change effective 5/68
Engine foreign object damage or seizure	046	469	211	8	Configuration change effective FY65 & sub aircraft

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Engine air intake filter cracked	047	200	0	5	Change effective 11/67
Transmission oil plug loose, leaking oil	048	63	0	1	Redesigned parts incorporated on FY66 & sub aircraft
Hydraulic inspection panel window cracked or broken	049	281	0	1	Redesigned parts incorporated on FY65 & sub aircraft
Forward roof window (RH) cracked	050	443	0	8	Configuration change effective FY67 & sub aircraft
Crew door windows or hinges broken	051	1490	0	8	Configuration change effective FY68 & sub aircraft
Tail rotor sprocket cover cracking or missing	052	4396	251	8	Configuration change effective FY63 & sub aircraft
Swash-plate ring assembly horn cracked	053	161	0	1	Redesigned parts incorporated FY67 & sub aircraft
Searchlight would not rotate, extend or retract	054	-	-	3	No corrective action
RPM warning system malfunctions	055	523	0	9	Change effective FY69 & sub aircraft

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Voltage regulator base contacts corroded	056	80	0	5	Change effective 4/68
Copilot attitude indicator inoperative	057	-	-	7	Not applicable
Shoulder harness inertia reel malfunctions	058	951	139	1	Redesigned reel incorporated on FY63 & sub aircraft
Clock inoperative	059	-	-	7	Not applicable
Engine mount tripod assembly cracked	060	-	-	3	No corrective action
Bellmouth rubbing and cutting lower engine pan	061	280	0	1	Redesigned installation incorporated on FY64 & sub aircraft
Swash-plate washer cupped/ excess play at support and ring	062	364	254	5	Change effective 10/67
Tail rotor installation boot torn or cut	063	-	-	6	No corrective action
Main rotor hub strap bushing rotated	064	-	-	3	No corrective action
Main rotor hub drag brace decal loose or missing	065	-	-	3	No corrective action

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Pilot and copilot seat material worn or frayed	066	1033	0	8	Change effective 4/65
Tail-boom fin access door hinge pin lost	067	1722	0	1	Change effective 3/65
AN/ARN 30 OMNI receiver set inoperative	068	-	-	7	Not applicable
Bleed air heater distribution system elbows deformed	069	-	-	7	Not applicable, retrofit
LH and RH fuel boost pump warn lights on, system clogged	070	1120	0	1	Redesigned parts incorporated on FY64 & sub aircraft
Collective lever has loose bushing or bearing	071	489	0	1	Manufacturing process change effective 7/65
42-degree gearbox leaking at input quill	072	7518	0	9	Change effective 1/64
Cargo panel door hinges broken/worn	073	-	-	3	No corrective action
Transmission fairing seal (-805-15) loose, bond failed	074	511	0	1	Redesigned parts incorporated 2/66
Swash-plate trunnion worn	075	472	383	5	Change effective 8/66

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Stabilizer bar lever bearing (AN201KP6A) failure/ malfunction	076	1450	0	1	Manufacturing process change effective FY67 & sub aircraft
Rotating (anticollision) light would not rotate	077	-	-	3	No corrective action
Lift link fitting loose on beam assembly (Lower trans- mission support)	078	-	-	4	Analysis not continued
Lift center beam (205-030- 845-3) cracked	079	-	-	4	Analysis not continued
Door jettison pin corroded	080	27.7	0	5	Change effective 2/67
Landing light would not retract or extend	081	-	-	3	No corrective action
FM homing antenna group (AN/ ARA-31) inoperative	082	-	-	7	Not applicable
External stores jettison lever support bent	083	-	-	7	Not applicable
Hydraulic reservoir internal components (body and rod) corroded	084	9.7	0	8	Change effective 7/65

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Roof work-deck has soft spots or holes	085	–	–	6	No corrective action
Hydraulic hoses chafing each other	086	–	–	4	Analysis not continued
Main rotor hub channel seals worn	087	–	–	4	Analysis not continued
Radio magnetic compass indicator inoperative (pilot)	088	–	–	7	Not applicable
Engine air inlet filter seal loose	089	673	412	1	Redesigned installation incorporated on FY65 & sub aircraft
Engine air inlet filter wire mesh loose	090	673	412	1	Redesigned installation incorporated on FY65 & sub aircraft
Excess play between collective lever and sleeve	091	–	–	3	No corrective action
Tail rotor control quill sprocket/guard/chain worn	092	–	–	3	No corrective action
Transmission drain line quick-disconnect fitting failure	093	–	–	6	No corrective action

TABLE 3. (Continued)

Problem	M&R index no.	λ_o x 10^6	λ_1 x 10^6	Notes	Comments
Tail-boom vertical fin access door hinge worn	094	–	–	3	No corrective action
Cargo panel hinged door spring stop broken	095	–	–	6	No corrective action
Intercom system inoperative (internal malfunction)	096	–	–	7	Not applicable
Extension light (D6810A) lamp burned out	097	–	–	6	No corrective action
Marker beacon receiver inoperative (R-1041/ARN)	098	–	–	7	Not applicable
Inlet filter frames bent when stepped on	099	–	–	6	No corrective action
Instrument panel pedestal support structure cracked	100	–	–	7	Not applicable
Main rotor hub pin moved downward and internal corrosion	101	–	–	4	Analysis not continued
Transmission mount damper worn, causes vibration	102	1032	254	5	Change effective 2/66
Synchronized elevator bell-crank bearing (FWD-902) failure	103	191	108	1	Redesigned part incorporated on FY66 & sub aircraft

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Synchronized elevator control idler bearing worn	104	319	292	9	New part incorporated on FY66 & sub aircraft
Aft fuselage bulkhead cracked at Station 243	105	-	-	6	No corrective action
5th transmission support cracked	106	1074	41	1	Redesigned part incorporated on FY63 & sub aircraft
Engine air induction screen fasteners broken	107	80	0	8	Configuration change effective FY68 & sub aircraft
Tail rotor slider worn	108	-	-	6	No corrective action
Threads stripped on tail rotor control tube or nut	109	120	0	5,9	TM change 11/67, new part incorporated on FY67 & sub aircraft
Hinged cargo panel window breaking	110	362	0	8	Configuration change effective 5/68
Dual tachometer inaccurate or inoperative	111	-	-	7	Not applicable
Pitot tube support assembly cracked	112	-	-	7	Not applicable
Airspeed indicator reading inaccurate	113	-	-	7	Not applicable

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Cargo floor damaged by sharp objects	114	–	–	6	No corrective action
Fasteners on tail rotor drive-shaft access doors worn	115	–	–	6	No corrective action
Engine work-deck panel bond failure	116	–	–	3	No corrective action
Scissors bearing AN201KP8A worn	117	–	–	6	No corrective action
Transmission mount boots cut/ mounts deteriorating	118	–	–	6	No corrective action
Armor seat panels protective strip bond failure	119	–	–	3	No corrective action
Stabilizer bar dampers - spline corroded/fluid dirty/ timing	120	–	–	6	No corrective action
Pilot attitude indicator inoperative	121	–	–	7	Not applicable
Transmission cowling seal (-805-13) loose - bond failure	122	255	0	1	Manufacturing process change effective FY66 & sub aircraft

TABLE 3. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
DECCA navigation system shorted - water leak at tail-boom attach point	123	-	-	7	Not applicable
Main transmission input quill leaking	124	40	0	1	Redesigned parts incorporated on FY69 & sub aircraft
FM receiver - transmitter (RT-348/ARC-54) inoperative	125	-	-	7	Not applicable
Crew-chief cord for intercom broken at plug	126	-	-	7	Not applicable
Magnetic brake malfunction	127	-	-	6	No corrective action
Emergency VHF transmitter T366A/ARC inoperative	128	-	-	7	Not applicable
Intercommunication system-radio cyclic grip switch inoperative	129	-	-	7	Not applicable
Microphone floor switch malfunction	130	-	-	7	Not applicable
Engine tachometer generators leaking oil at base	131	-	-	7	Not applicable
Transmission oil pressure switch inoperative	132	-	-	3	No corrective action

TABLE 3. (Concluded)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Fuel boost pump (air-driven) inoperative/leaks	133	-	-	4	Analysis not continued

Notes:

1. Hardware redesigned/manufacturing process modified; resulted in reduced failure rate.
2. No feasible solution exists; problem not corrected.
3. Solution still pending at end of M&R Program.
4. Problem not considered significant.
5. TM procedure change released; resulted in reduced failure rate.
6. Corrective action rejected by the customer.
7. Problems associated with navigation, avionics, communications, and weapons systems are not applicable to this project.
8. Configuration change resulted in reduced failure rate.
9. Vendor-supplied part change resulted in reduced failure rate.

TABLE 4. AH-1G M&R PROBLEM SUMMARY

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Skid shocs wear out when used for training	601	-	-	7	Not applicable
Attitude indicator malfunctions	602	-	-	7	Not applicable
Pylon damper internal failure causes rivet failure	603	1129	296	1	Change made on ship 67-15534
Tail light fairing broken or cracked	604	969	0	8	ECP effective ship 67-15702
Engine tail pipe brackets cracked/broken	605	604	296	1	Change effective ship 66-15283
Standoffs allow transmission cowl to scratch canopy	606	-	-	7	Not applicable
Oil cooling fan blower coupling fail/deteriorate	607	1542	0	8	ECP effective ship 67-20282
Oil cooler blower installation failures	608	1987	0	1	Change effective ship 67-15618
Tail light bulb burned out	609	2035	0	8	ECP effective ship 67-15702
42- and 90-degree gearboxes damaged internally	610	1328	443	8	ECP approved 5/69
Engine oil level low, bypass light on	611	225	0	8	ECP approved 1/68

TABLE 4. (Continued)

Problem	M&R index no.	λ_o x 10^6	λ_1 x 10^6	Notes	Comments
Scissor bushing worn by main rotor pitch-link bearing	612	2893	0	1,5	ECP approved 10/68
DC voltage regulator malfunction	613	620	0	8	Change effective ship 67-15534
Cockpit light loose/bond failure	614	997	57	8	Change effective FY66 ships
UHF receiver-transmitter inoperative	615	-	-	7	Not applicable
VHF transceiver (AN/ARC-134) inoperative/weak	616	-	-	7	Not applicable
Anticollision light bulb burned out	617	-	-	3	PIP task proposal in work 6/70
Main rotor hub and blades out of track/balance	618	-	-	3	MTBF recorded as 3800 2/70
Mast spinner chafing main rotor pitch control tubes	619	64	0	8	Change effective ship 66-15293
SAS malfunctions in roll channel	620	6081	2027	8	ECP approved 7/68
Altitude indicator sticks/ inoperative	621	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Flapping main rotor blade damages ship	622	386	284	5	New TM 11/68
FM transceiver (TR-348/ARC-54) inoperative	623	-	-	7	Not applicable
Improper flight control friction	624	-	-	7	Not applicable
Engine deck has voids/bonding separation	625	64	0	1	EO effective ship 66-15259
Skid gear damaged during hard landing	626	450	227	1	ECP approved 1/68
Rain removal air melts windshield	627	48	0	1	Change effective ship 68-15000
Pilot sight bulb burned out	628	-	-	7	Not applicable
Tail rotor hydraulic boost cylinder leaking	629	-	-	3	Change suggested 2/70
Plastic rub strips loose on ammo compartment door	630	804	483	8	EO effective ship 67-15450
Pilot door difficult to open/close	631	558	186	1	EO effective ship 69-16410
Canopy door seals leak water	632	190	0	1	ECP effective ship 68-15000

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Cross-tube assembly fairing cracked	633	1272	0	8	Change effective ship 68-15000
Tail rotor pitch change link bearings loose	634	1828	592	1	EO approved 9/68
Oil cooler blower foreign object damage	635	95	0	8	ECP approved 2/68
Tail rotor hub and blades out of track	636	-	-	3	Still monitoring 2/70
Transmission oil line chafed/improper hose clamp installed	637	111	592	8	EO effective ship 66-15296
Smoke grenade door too heavy/damages skin	638	-	-	7	Not applicable
Side panel angle (209-030-102-37 and -173) cracked	639	-	-	7	Not applicable
SCAS light on/null adjustment improper	640	-	-	3	Still monitoring 2/70
SAS unstable when VHF keyed	641	45	0	1	ECP approved 8/68
Main drive shaft causing vibration/inadequate lubrication	642	-	-	4	Closed - insignificant

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Tail rotor drive shaft out of round	643	30	0	8	ECP approved 2/68
Tail rotor hanger bearing seal failure	644	700	0	9	Vendor action effective 4/68
Cockpit light bulb burned out	645	–	–	3	Investigation continues 2/70
Wing navigation light bulb burned out	646	–	–	3	PIP task submitted 2/70
Dual tachometer inoperative or erratic	647	–	–	7	Not applicable
Airspeed indicator inoperative	648	–	–	7	Not applicable
Engine idle stop solenoid malfunction	649	–	–	7	Not applicable
Main rotor hub sand deflector cracking in service	650	–	–	3	Analysis in progress 2/70
Oil cooler fitting leaking/ fitting cracked	651	96	0	1	Change effective 4/68
Internal failure of inter-valometer	652	–	–	7	Not applicable
Main transmission input quill leaking	653	2973	991	8	ECP approved 4/68

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Tail rotor cables frayed or worn	654	3697	1232	1	ECP approved 9/69
N2 tachometer generator inoperative	655	-	-	7	Not applicable
Impedance pad defective	656	-	-	7	Not applicable
RPM warning box malfunctions	657	1765	588	1	ECP approved 9/69
Engine linear actuator malfunctions	658	-	-	3	SEM review 2/70
Main rotor blade cobalt leading-edge strip bonding fails	659	196	65	1	EO issued 4/68
Main rotor trunnion sleeve and trunnion bearings worn	660	-	-	3	ECP rejected by Army 1/69
TAT-102A crossover drive cable malfunctions	661	-	-	7	Not applicable
Main drive shaft coupling failures	662	-	-	1	ECP effective ship 66-15283
Main rotor trunnion housing attach bolts sheared/ears fretting	663	64	21	1	EO effective ship 67-15665
Tail rotor slider boot torn	664	-	-	6	ECP rejected by Army 1/68

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Main inverter failures	665	1510	0	1	ECP approved 2/68
Anticollision light will not rotate	666	-	-	3	PIP task proposed 6/70
Exhaust temperature gage malfunctions	667	-	-	7	Not applicable
Engine tail pipe fairing difficult to remove	668	-	-	7	Not applicable
Drive shaft covers chafe tail fin and tailboom	669	-	-	3	Additional information requested 2/70
Armament debris damages tail fin and tail rotor blades	670	-	-	3	Analysis in progress 2/70
Oil cooler blower chafes drive shaft clamp	671	145	0	8	ECP approved 2/68
Torquemeter fluctuates or inoperative	672	-	-	7	Not applicable
Radio magnetic indicator (RMI) inoperative	673	-	-	7	Not applicable
TAT-102A turret cowl Cam-lock fasteners broken	674	-	-	7	Not applicable
Pilot door frame cracked	675	365	0	1	EO issued 2/68

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Pilot and gunner step cap unbonded	676	546	0	8	Change effective ship 66-15283
Pulley bracket pin hole elongated	677	111	0	1	Change effective ship 67-15786
Main rotor pitch change link bearing worn	678	1569	523	1	EO issued 11/68
Spare inverter failures	679	1797	0	8	ECP approved - ship 68-15000
Instrument light rheostat defective	680	-	-	3	Investigation to continue 2/70
Navigation light flasher inoperative	681	-	-	3	PIP task proposed 2/70
Fuel boost pump failures	682	-	-	3	Investigation to continue 2/70
Gunner attitude indicator has air bubbles	683	-	-	7	Not applicable
Gunner mirror loose	684	-	-	4	Closed - insignificant
Pilot seat ventilation duct problems	685	-	-	6	ECP rejected 9/68
Gunner sight light bulb burned out	686	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Nones	Comments
Wing pylon fairing Dzuz fasteners broken	687	-	-	4	Closed - insignificant
XM-18 minigun pod malfunctions	688	-	-	7	Not applicable
MB-1 attitude indicator inoperative	689	-	-	7	Not applicable
Engine malfunctions	690	-	-	3	Additional information needed 2/70
XM-18 minigun pod inoperative/ batteries discharged	691	-	-	7	Not applicable
Battery will not hold charge	692	-	-	3	AVSCOM to make recommendation 2/70
Engine tail pipe ejector/ drain line cracked	693	875	0	8	EO effective ship 68-15000
Insufficient emergency collective hydraulic boost	694	48	0	8	ECP approved 8/68
Air duct elbow cracked	695	556	0	8	Change effective ship 67-15534
TAT-102A crossover malfunctions	596	-	-	7	Not applicable
Pilot sight loose	697	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_c \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Smoke grenade dispenser inoperative	698	-	-	7	Not applicable
XM-159 rocket pod malfunctions	699	-	-	7	Not applicable
Friction collet set fingers broken	700	610	284	1	EO effective ship 67-15450
Gunner collective stick boost hangs on console	701	16	0	1	Change effective ship 67-15603
90-degree gearbox mounting studs broken	702	207	0	1	SEM issued 10/68
Fuel pressure transmitter mount deteriorated	703	1026	342	1	EO effective ship 68-17032
Main rotor blade cracked through skin and filler	704	75	25	1	ECP approved ship 68-15211
Skid tubes damaged/bent flat	705	785	261	1	EO issued 9/68
AC voltage erratic	706	-	-	7	Not applicable
Pilot seat adjustment lever broken	707	211	0	1	Change approved ship 67-15786
Gunner door hard to latch	708	588	196	1	EO issued ship 69-16410

TABLE 4. (Continued)

Problem	M&R index no.	λ_o x 10^6	λ_1 x 10^6	Notes	Comment
Skid tube attachment bolts loose	709	1640	142	1	Change approved ship 66-15300
Transmission cowl standoff clips break	710	-	-	4	Closed - insignificant
Pylon damper leaking oil	711	-	-	3	Procedure change pending 2/70
42-degree gearbox cover cracked/deformed	712	830	276	1	EO issued 2/70
Tail rotor controls out of rig	713	181	60	5	TM revised 6/69
Battery cable chafes aft wall of battery compartment	714	96	0	8	SEM issued 10/68
Cockpit and instrument lights out/defective wiring	715	-	-	3	ECP submitted to Army 3/70
Oil leak at N2 tachometer generator/defective seal	716	-	-	7	Not applicable
Intercommunication control inoperative	717	-	-	7	Not applicable
Vent fan blades cracked/bent/loose	718	196	65	1	PCA approved ship 69-20880
Pylon sway brace bolt broken	719	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
TAT-102A will not fire/ electrical malfunctions	720	-	-	7	Not applicable
TAT-102A turret mechanical malfunctions	721	-	-	7	Not applicable
Turn and slip indicator inoperative	722	-	-	7	Not applicable
Engine mount support bearing has excessive play	723	715	296	1	EO issued ship 67-15534
Swash plate has play on uniball	724	254	84	5	SEM issued 10/68
Hydraulic servo cylinder loose in housing	725	528	176	1	EO issued 11/69
Floor microphone switch inoperative	726	-	-	7	Nct applicable
Engine/transmission cowling sealing strips unbonded	727	482	85	8	Change effective ship 66-15305
Cowling hinge chafes trans- mission case	728	-	-	4	Closed - insignificant
Crosstube-fuselage fairing loose/unbonded	729	-	-	3	Analysis still in progress 6/70
Tail skid tube loose	730	-	-	4	Closed - insignificant

TABLE 4. (Continued)

Problem	M&R index no.	λ_o x 10^6	λ_1 x 10^6	Notes	Comments
Tail fin access door hinge worn/broken	731	785	261	8	ECP approved 5/69
Friction collet loose/nut backed off	732	2550	850	1	ECP approved 2/70
Instrument panel light control knob loose/broken	733	-	-	3	Analysis still in progress 2/70
Hydraulic line fittings leak	734	238	79	1	EO issued 5/69
Clock intermittently inoperative	735	-	-	7	Not applicable
Engine scavenge oil line leaks	736	-	-	7	Not applicable
RT-494/APX-44 transponder inoperative	737	-	-	7	Not applicable
Cabin air inlet elbow duct flange separated	738	222	0	1	Change effective ship 67-15547
TAT-102A turret control box malfunctions	739	-	-	7	Not applicable
Caution panel defective	740	-	-	3	Data package being prepared 7/69
XM-18 bullet splinters damage aircraft	741	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Lift link broken	742	45	0	1	EO issued ship 68-17032
Air inlet screen actuator malfunction	743	318	296	9	Vendor corrected 8/68
Synchronized elevator has excess play between horn	744	-	-	4	Closed - insignificant
Swash plate antidrive bell-crank bushing worn	745	-	-	3	Data package being prepared 8/68
Tail rotor chain worn	746	528	176	8	ECP approved 6/69
Swash plate spring bracket loose/bond failure	747	-	-	4	Closed - insignificant
FM inoperative due to defective wiring/antenna	748	-	-	7	Not applicable
Main drive shaft seal leaking	749	-	-	3	PIP task submitted 4/70
Searchlight will not extend/retract/rotate	750	-	-	3	AVSCOM to investigate 2/70
Control tube chafes hydraulic lines	751	48	0	1	EO issued 4/69
Dual tachometer wiring discrepancies	752	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Outside air temperature thermometer malfunction	753	–	–	7	Not applicable
Airspeed indication system gives erratic readings	754	–	–	7	Not applicable
Generated cooling air hose chafes cowl armor plate	755	91	31	1	SEM released 3/69
Wing stores circuit breaker malfunctions	756	–	–	7	Not applicable
Directional gyro (CN-998/ANS-43) malfunctions	757	–	–	7	Not applicable
UHF (ARC-51BX) control panel malfunctions	758	–	–	7	Not applicable
VHF control panel (ARC-134) malfunctions	759	–	–	7	Not applicable
Canopy breakout knife/tool rusty	760	–	–	4	Closed - insignificant
Engine deck inserts for hanger support loose/broken	761	175	0	8	SEM released 6/70
XM-28 crossover inoperative and/or jammed	762	–	–	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Ammunition compartment doors cracked/loose rivets	763	-	-	3	Continue to monitor 2/70
Particle separator filter latch broken/loose rivet	764	317	106	1	ECP approved ship 66-15249
Tail rotor control quill binds/sprocket worn	765	558	186	8	ECP approved 6/69
SCAS amplifier malfunctions in pitch/yaw channel	766	413	296	1	EO released 11/68
Instrument panel light bulbs burned out	767	-	-	3	ECP submitted to Army 3/70
Side tail light bulb burned out	768	-	-	3	PIP task proposed 2/70
Searchlight bulb burned out	769	-	-	3	PIP task proposed 2/70
Engine foreign object damage	770	75	25	1	ECP approved ship 66-15249
Engine oil pump intake hose chafes engine case	771	-	-	3	Data package being prepared 11/68
Main rotor hub outboard grip bearing worn/seal failure	772	-	-	3	AVSCOM to investigate 2/70
Tail fin drive shaft cover cracked	773	196	65	8	ECP approved 6/69

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Shoulder harness inertia reel malfunctions	774	-	-	3	No corrective action 6/70
Tail rotor hub bearings rough or worn	775	-	-	3	AVSCOM to review ECP 2/70
SCAS pylon compensation unit malfunctions	776	-	-	3	Evaluation of mod, units pending 6/70
42-degree gearbox leaking at input quill	777	-	-	3	Continuing investigation 2/70
Instrument panel lights/ transistor defective	778	-	-	3	AVSCOM to review ECP 2/70
Navigation light inoperative/ wire broken	779	350	0	8	ECP approved ship 67-15786
Wing navigation light lens broken	780	-	-	3	PIP task requested 2/70
Cross-tube cap assembly rubber pad loose/missing	781	620	0	9	EO approved for vendor part ship 68-15000
Tail rotor hub spindle fretting/damaged/cracked	782	45	15	1	ECP approved 12/68 ship 68-15188
Pilot override cylinder leaking/binding	783	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Transmission oil line (filter-to-manifold) cracked/leaks	784	91	30	1	ECP approved 3/69 ship 69-16410
Accumulator pressure improper	785	196	65	9	PCA approved ship 69-16410
Flight control servo leaks externally/internally	786	-	-	3	Analysis being performed 2/70
Feedback from tail rotor servo	787	-	-	3	Procurement specification change coming 2/70
Oil leak at N1 tach generator	788	-	-	7	Not applicable
N1 tach indicator inoperative	789	-	-	7	Not applicable
Transmission oil thermobulb malfunctions	790	-	-	7	Not applicable
Fuel quantity indicator inoperative	791	-	-	7	Not applicable
Attitude indicator rate switching gyro defective	792	-	-	7	Not applicable
Pilot RMI compass internal bulb burned out	793	-	-	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
ADF(ARN-83) receiver malfunction	794	-	-	3	Not applicable
Tail rotor hub and blades and 90-degree gearbox lost in flight	795	-	-	3	Investigation to continue 2/70
Main rotor trunnion housing attaching bolts loose	796	-	-	3	Investigation to continue 6/70
Tail fin access door Dzus fasteners loose/broken	797	-	-	3	Data review to continue 2/70
Tail rotor cable fairleads worn	798	377	125	8	ECP approved 9/69
Swashplate bearing retainer nuts loose	799	-	-	3	Investigation to continue 2/70
Turret weapon circuit breaker malfunctions	800	-	-	7	Not applicable
Fuel boost pump warning switch malfunctions	801	-	-	3	Data review to continue 2/69
Gearbox chip detector damaged	802	-	-	3	Data review to continue 2/69
Chip detector wire broken/ loose	803	-	-	3	Data review to continue 9/69

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Minigun malfunctions/dirty/ lack of lubrication	804	–	–	7	Not applicable
Wing pod lost in flight	805	–	–	7	Not applicable
Tail rotor slider worn	806	–	–	6	ECP rejected 3/69
XM-28 electronic control unit malfunctioning	807	–	–	7	Not applicable
XM-28 7.62mm drive cable malfunctions	808	–	–	7	Not applicable
40mm launcher drive cable malfunctions	809	–	–	7	Not applicable
XM-28 minigun turret malfunctions	810	–	–	7	Not applicable
XM-73 pilot sight inopera- tive/bulb burned out	811	–	–	7	Not applicable
40mm grenade launcher malfunctions	812	–	–	7	Not applicable
XM-28 clearing time delay relay malfunctions	813	–	–	7	Not applicable
Main rotor blade grip cracked	814	–	–	4	Closed – insignificant

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Engine tripod rod-end bearings worn	815	724	241	1	Change effective 2/70
Fifth mount support (246-13) cracked	816	151	50	1	EO issued 7/69
Swashplate bearings worn/ throws lubrication	817	-	-	3	Data review to continue 4/69
Tail rotor crosshead chafed by tail rotor pitch change link bearing	818	-	-	2	Closed - no solution
Mast damaged or scored	819	75	25	5	SEM issued 4/69
Main rotor hub extension sleeve cracked	820	-	-	3	Data review to continue 4/69
Starter/generator inoperative	821	-	-	3	AVSCOM to investigate 2/70
Generator field relay malfunction	822	-	-	3	Data review to continue 4/69
Anticollision light came off/screws vibrate loose	823	-	-	3	PIP task requested 2/70
Landing light bulb burned out	824	127	0	8	PCA issued ship 67-15618

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Transmission oil level light bulb burned out	825	–	–	4	Closed – insignificant
Fuel boost pump circuit breaker malfunctions	826	–	–	3	Data review to continue 4/69
Hydraulic pump internal malfunction	827	–	–	3	Data review to continue 4/69
Engine oil pressure transmitter malfunctions	828	–	–	7	Not applicable
Engine oil indicator malfunctions	829	–	–	7	Not applicable
Linear actuator rod-end bearing frozen	830	–	–	3	Data review to continue 5/69
Collective collet dust boot torn	831	–	–	3	Data review to continue 5/69
FM control unit malfunction	832	–	–	7	Not applicable
Transmission oil pressure warning switch inoperative	833	287	96	1	EO issued 5/69 ship 68-17114
40mm ammunition/links defective	834	–	–	7	Not applicable
Transmission lift link lug cracked/broken	835	–	–	3	AVSCOM to review SEM 2/70

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Lower scissor link bearing (-449-1) worn	836	-	-	3	Data review to continue 5/69
Canopy door handhold loose/broken	837	-	-	3	Data review to continue
Gunner door hinge broken/blunder	838	-	-	4	Closed - insignificant
Pilot door handle came off/loose	839	211	70	1	EO issued 6/69 ship 69-16410
Ammunition door interior has holes/FOD/mishandled	840	-	-	3	Data review to continue 6/69
Main rotor blade has bonding voids	841	-	-	3	Data review to continue 6/69
Tail rotor cable pulley cracked/broken	842	-	-	4	Closed - insignificant
N1 tachometer generator inoperative	843	-	-	7	Not applicable
Fifth mount support Dzus fasteners clips rivets loose	844	-	-	3	Data review to continue 6/69
Tail rotor drive shaft damaged by misrigged tail rotor cable	845	-	-	4	Closed - insignificant

TABLE 4. (Continued)

Problem	M&R index no.	λ_o x 10^6	λ_1 x 10^6	Notes	Comments
Inverter select switch malfunction	846	-	-	4	Closed - insignificant
Cross-tube fairing (1-piece) cracked/lost in flight	847	572	296	1	EO issued 6/69 ship 68-15000
Excessive pylon rock/worn SGT 1270-1 damper	848	-	-	3	Investigation to continue 2/70
Engine oil temperature thermobulb malfunctions	849	-	-	7	Not applicable
Engine overspeed governor malfunctions	850	-	-	4	Closed - insignificant
Lateral magnetic brake binds/ internal malfunction	851	106	35	1	Change effective 2/70
Sand deflector scratches yoke	852	-	-	3	Data review to continue 7/69
Hydraulic caution light stays on/pressure switch inoperative	853	-	-	4	Closed - insignificant
Engine oil temperature indicator malfunctions	854	-	-	7	Not applicable
Engine chip detector plug damaged/malfunction	855	-	-	4	Closed - insignificant

TABLE 4. (Continued)

Problem	M&R index no.	λ_o x 10^6	λ_1 x 10^6	Notes	Comments
Engine oil pressure warning switch malfunctions	856	270	0	1	EO issued 7/69 ship 68-15000
Transmission oil bypass pressure switch defective	857	–	–	3	Data review to continue 7/69
XM-157 rockets firing contacts bad	858	–	–	7	Not applicable
Friction collet sleeve unbonded from mast	859	–	–	3	Data review to continue 8/69
Gunner sight station light bulb burned out	860	–	–	7	Not applicable
Tail fin has loose rivets	861	–	–	3	Data review to continue 8/69
90-degree gearbox leaking at input quill	862	–	–	3	Data review to continue 8/69
FM homing antenna tape damaged by pilot helmet	863	–	–	7	Not applicable
Engine fuel pressure warning switch failure	864	–	–	4	Closed - insignificant
7.62mm ammunition chute bent/broken	865	–	–	7	Not applicable

TABLE 4. (Continued)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
Engine igniter plugs defective	866	-	-	4	Closed - insignificant
Gunner door frame cracked	867	-	-	3	SEM not feasible 6/70
Cross-tube fairing step broken/loose	868	207	69	1	EO issued 9/69 - ship 68-15000
Emergency collective solenoid valve malfunctions	869	-	-	3	Analysis to continue 2/70
DC volt/amp meter glass broken	870	-	-	7	Not applicable
XM-129 weapon controller malfunctions	871	-	-	7	Not applicable
Outboard bore-sight link sheared	872	-	-	7	Not applicable
Standby inverter circuit breaker malfunctions	873	-	-	3	Data review to continue 9/69
42-degree gearbox cover Dzus fasteners lost/broken	874	-	-	3	Data review to continue 9/69
Cabin air ventilation duct cracked	875	-	-	3	Data review to continue 9/69
RT-859/APX-72 transponder set inoperative	876	-	-	7	Not applicable

TABLE 4. (Concluded)

Problem	M&R index no.	$\lambda_o \times 10^6$	$\lambda_1 \times 10^6$	Notes	Comments
40mm launcher drive motor malfunctions	877	–	–	7	Not applicable
Gunner door strut inoperative	878	–	–	3	Data review to continue 10/69
90-degree gearbox leaking at output quill	879	–	–	4	Closed - insignificant
Collective servo boot torn/cracked/deteriorated	880	–	–	3	Data review to continue 4/69
Tail rotor push-pull bell-crank (722-1) worn	881	–	–	3	Data review to continue 11/69
Oil level light switch defective	882	–	–	4	Closed - insignificant
Pillow block does not clamp trunnion bearing	883	–	–	3	Data review to continue 11/69

Notes:
1. Hardware redesigned/manufacturing process modified; resulted in reduced failure rate.
2. No feasible solution exists; problem not corrected.
3. Solution still pending at end of M&R Program.
4. Problem not considered significant.
5. TM procedure change released; resulted in reduced failure rate.
6. Corrective action rejected by the customer.
7. Problems associated with navigation, avionics, communications, and weapons systems are not applicable to this project.
8. Configuration change resulted in reduced failure rate.
9. Vendor-supplied part change resulted in reduced failure rate.

AH-1G MONITORED AIRCRAFT

BELL SERIAL NUMBER	MILITARY SERIAL NUMBER	LOCATION	STARTED MONITORING DATE DA.MO.YR.	STARTED MONITORING A/C TIME	STOPPED MONITORING DATE DA.MO.YR.	STOPPED MONITORING A/C TIME	REMARKS
20151	67-15487	NET TEAM RVN	19 05 68	21	10 10 68	314	CRASHED
20154	67-15490	NET TEAM RVN	01 05 68	22	12 09 68	257	EXPLOSION IN TURRET
20155	67-15491	NET TEAM RVN	01 05 68	22	28 02 69	549	DAMAGED WHILE BEING AIRLIFTED
20156	67-15492	334TH BIEN HOA	04 07 68	30	12 02 69	380	CRASHED
20158	67-15494	NET TEAM RVN	25 03 68	15	10 01 69	690	CRASHED
20159	67-15495	NET TEAM RVN	26 03 68	17	28 02 69	631	COMBAT DAMAGE
20160	67-15496	NET TEAM RVN	25 03 68	7	31 10 70	1134	PROGRAM TERMINATION
20161	67-15497	NET TEAM RVN	26 03 68	17	09 09 69	1092	CRASHED
20168	67-15504	235TH CAN THO	10 06 68	26	31 09 68	252	MONITOR RETURNED TO CONUS
		235TH CAN THO	15 10 68	292	31 10 70	1225	PROGRAM TERMINATION
20169	67-15505	235TH CAN THO	12 02 69	315	31 10 70	893	PROGRAM TERMINATION
20174	67-15510	235TH CAN THO	11 02 69	159	30 05 69	461	IN FLIGHT FAILURE
20202	67-15538	334TH BIEN HOA	17 06 68	18	31 05 69	453	COMBAT DAMAGE-CRASHED
20205	67-15541	334TH BIEN HOA	20 06 68	19	31 10 70	1098	PROGRAM TERMINATION
20208	67-15544	235TH CAN THO	16 11 68	232	13 01 69	358	COMBAT DAMAGE
20210	67-15546	334TH BIEN HOA	30 06 68	87	28 02 69	444	COMBAT DAMAGE
20211	67-15547	334TH BIEN HOA	22 06 68	23	31 10 70	1098	PROGRAM TERMINATION
20212	67-15548	334TH BIEN HOA	20 06 68	22	01 04 69	527	DROPPED
20220	67-15556	334TH BIEN HOA	07 07 68	21	24 01 69	455	COMBAT DAMAGE
20226	67-15562	334TH BIEN HOA	17 06 68	26	31 10 70	896	PROGRAM TERMINATION
20230	67-15566	235TH CAN THO	09 11 68	264	29 07 69	991	BATTLE DAMAGE
20270	67-15606	235TH CAN THO	01 08 68	18	31 10 70	1084	PROGRAM TERMINATION
20272	67-15608	235TH CAN THO	01 08 68	18	31 10 70	1144	PROGRAM TERMINATION
20278	67-15614	235TH CAN THO	01 09 68	91	30 09 68	149	MONITOR RETURNED TO CONUS
		235TH CAN THO	15 10 68	171	31 10 70	1165	PROGRAM TERMINATION
20281	67-15617	235TH CAN THO	01 09 68	88	30 09 68	174	MONITOR RETURNED TO CONUS
		235TH CAN THO	15 10 68	191	13 01 69	433	COMBAT DAMAGE
20283	67-15619	235TH CAN THO	01 09 68	34	30 09 68	88	MONITOR RETURNED TO CONUS
		235TH CAN THO	15 10 68	130	13 01 69	346	COMBAT DAMAGE
20298	67-15634	NET TEAM RVN	08 09 68	22	31 10 70	985	PROGRAM TERMINATION
20310	67-15646	235TH CAN THO	01 08 68	39	31 10 70	1033	PROGRAM TERMINATION
20345	67-15681	NET TEAM RVN	20 10 68	15	28 12 68	214	CRASHED
20348	67-15684	334TH BIEN HOA	12 10 68	17	31 10 70	992	PROGRAM TERMINATION
20349	67-15685	334TH BIEN HOA	01 12 68	124	31 10 70	902	PROGRAM TERMINATION
20355	67-15691	334TH BIEN HOA	12 10 68	14	31 10 68	35	COMBAT DAMAGE
20435	67-15771	235TH CAN THO	01 06 69	249	31 10 70	609	PROGRAM TERMINATION
20437	67-15773	334TH BIEN HOA	01 02 69	170	31 10 70	859	PROGRAM TERMINATION
20439	67-15775	235TH CAN THO	01 06 69	166	31 10 70	545	PROGRAM TERMINATION
20444	67-15780	235TH CAN THO	01 06 69	358	31 10 70	737	PROGRAM TERMINATION
20449	67-15785	NET TEAM RVN	14 01 69	17	31 10 70	732	PROGRAM TERMINATION
20450	67-15786	NET TEAM RVN	30 12 68	31	31 10 70	861	PROGRAM TERMINATION
20463	67-15799	235TH CAN THO	07 10 69	478	31 10 70	554	PROGRAM TERMINATION
20468	67-15804	334TH BIEN HOA	12 02 69	16	31 10 70	699	PROGRAM TERMINATION

Figure 1. Example of monitored aircraft time base computer listing.

BY ______	BELL HELICOPTER COMPANY POST OFFICE BOX 482 • FORT WORTH 1, TEXAS	MODEL UH-1D PAGE C-28.1
CHECKED ______		RPT 205-099-157 Rev. C

Date: 1 September 1966
Status: Closed

C. Problem Analyses, Corrective Action Summary & Recommendations (Cont'd)

28. AN201KP8A Bearing Loose in Scissors Lever (CIC-730-920-001)

System or Component Description

The scissors and sleeve assembly and the swashplate and support assembly are installed together around the mast at top of transmission. These assemblies act as a unit which transmits movements from cyclic and collective control systems to linkages which rotate with main rotor. Collective sleeve moves vertically within swashplate support as actuated by collective control stick. Swashplate, mounted on a universal support, is for tilt according to cyclic input. Combined effect on scissor levers and upper linkage determines rotor tilt and blade pitch.

Failure Mode

The AN201KP8A pivot bearing is installed as a floating bearing in the 204-011-406-5 lever. After operating in a sand environment excess play between the bearing and lever bore develops. If left unchecked, the scissor lever wear is accelerated by entrance of sand which acts as an abrasive. Excessive looseness (radial) develops and vibration occurs. To remedy the condition, usually a new scissors lever and bearing are required with minimum ship downtime of nearly five hours.

Corrective Action

Oct. 1964 thru April 1966

A Class II change, adding a steel sleeve between the bearing outer surface and the scissor lever bore, was incorporated on UH-1D 64-13598 and subsequent production and on all spares purchased by Bell after January 1965. This change created a 204-011-406-9 scissor, thus the new scissor replaced the old 204-011-406-5 scissor.

To provide repair instructions for field units, Bell Helicopter Company released a field fix, SEM 204-64-25. The service instruction issued in April 1964 was released to the depots making repairs. The above corrective action resolves this problem.

Figure 2. Example of M&R problem narrative.

BELL HELICOPTER COMPANY
M. AND R. PROGRAM
UH-1 SERIES HELICOPTERS

COMPONENT FAILURE INFORMATION PAGE NO 122-A
CONCISE FIELD FAILURE/DISCREPANCY REPORT LISTING
PART NUMBER SEQUENCE

REPORT DATE	AIRCRAFT MIL S/N	A/C MOD	SHIP TIME	NO RPT	TYPE OF OCCR	PRI OR SEC	SYS FAL	PART NUMBER	PART SER NO	PART NAME AND IDENTIFICATION	PART TIME	PROBLEM FILE NUMBER	REPORT NUMBER
020668	66-15314	G	0202	01	FAIL	PRI	NO	SGT1270-1		AFT PYLON DAMPER ASSY,R/H	0202	ALG-780-370-290	FDRGB0457
040668	66-15326	G	0196	01	FAIL	PRI	NO	SGT1270-1	331	AFT PYLON DAMPER ASSY,R/H	0196	ALG-780-370-290	FDRGB0484
040668	66-15326	G	0196	01	FAIL	PRI	NO	SGT1270-1	246	AFT L/H PYLON DAMPER ASSY	0196	ALG-780-370-290	FDRGB0485
050668	67-15494	G	0146	01	FAIL	PRI	YES	SGT1270-1	367	AFT PYLON DAMPER ASSY,L/H	0146	ALG-780-370-290	FDRNG1393
070668	67-15494	G		01	FAIL	PRI	YES	SGT1270-1	367	AFT.MOUNT DAMPER ASSY.	0142	ALG-780-370-290	EIREG0934
100568	66-15300	G	0340	02	FAIL	PRI	YES	SGT1270-1		AFT MOUNT DAMPER ASSY.		ALG-803-502-290	FDRGA0631
130669	66-15275	G	0436	01	FAIL	PRI	NO	SGT1270-1	83	AFT MOUNT DAMPER ASSY.	0436	ALG-780-370-290	CSOC21950
130668	66-15275	G	0436	01	FAIL	PRI	NO	SGT1270-1	74	AFT MOUNT DAMPER ASSY.	0436	ALG-780-370-290	CSOC21951
180668	67-15551	G	0215	01	FAIL	PRI	NO	SGT1270-1	239	AFT.MOUNT DAMPER ASSY.	0215	ALG-780-370-290	CSOC21948
190668	67-15494	G		01	FAIL	PRI	NO	SGT1270-1		AFT.MOUNT DAMPER ASSY.	0184	ALG-780-370-290	EIREG0918
190668	67-15494	G	0146	01	FAIL	PRI	NO	SGT1270-1	367	AFT MOUNT DAMPER ASSY.	0146	ALG-780-370-290	CSOC21947
190668	67-15497	G	0191	01	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY.	0191	ALG-381-920-290	FDRNG1420
210668	66-15322	G	0255	02	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY.	0255	ALG-381-920-290	FDRGB0577
240669	67-15491	G	0066	01	FAIL	PRI	NO	SGT1270-1	1403	AFT MOUNT DAMPER ASSY.	0066	ALG-381-920-290	FDRNG1434
020768	66-15333	G	0346	01	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY,L/H		ALG-381-920-290	FDRGA0617
040768	67-15491	G		01	FAIL	PRI	NO	SGT1270-1		AFT.MOUNT DAMPER ASSY.	0079	ALG-690-020-290	EIREG0950
040769	67-15497	G		01	FAIL	PRI	NO	SGT1270-1		AFT.MOUNT DAMPER ASSY.	0187	ALG-690-020-290	EIREG0951
130769	67-15497	G	0253	01	FAIL	PRI	NO	SGT1270-1	410	AFT MOUNT DAMPER ASSY,R/H	0253	ALG-381-920-290	FDRNG1491
170768	67-15496	G	0257	01	FAIL	PRI	NO	SGT1270-1	408	AFT MOUNT DAMPER ASSY,L/H	0257	ALG-381-920-290	FDRNG1509
190768	66-15278	G	0646	02	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY		ALG-690-020-290	FDRG21257
310768	66-15266	G	0524	01	FAIL	PRI	NO	SGT1270-1	581	AFT MOUNT DAMPER ASSY		ALG-690-020-290	FDRGG1384
020869	66-15286	G	0495	01	FAIL	PRI	NO	SGT1270-1	607	AFT MOUNT DAMPER ASSY		ALG-381-920-290	FDRGG1499
240868	66-15253	G	0053	02	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY.	0053	ALG-780-370-290	EIREG0827
130968	66-15269	G	0889	01	FAIL	PRI	NO	SGT1270-1		AFT.MOUNT DAMPER ASSY.		ALA-730-105-290	FDRG20687
130968	66-15269	G	0642	01	FAIL	PRI	NO	SGT1270-1	587	AFT MOUNT DAMPER ASSY		ALG-690-020-290	FDRGG1546
150968	66-15249	G	0228	01	FAIL	PRI	YES	SGT1270-1	4	R/H AFT MOUNT DAMPER ASSY	0228	ALG-780-370-290	EIREG0065
160968	67-15494	G	0359	01	FAIL	PRI	NO	SGT1270-1	962	AFT MOUNT DAMPER ASSY	0359	ALG-381-920-290	FDRNG1663
200968	66-15333	G	0465	02	FAIL	PRI	YES	SGT1270-1	894	AFT MOUNT DAMPER ASSY	0266	ALG-690-020-290	FDRGA0835
260968	66-15305	G	0494	02	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY	0219	ALG-780-370-290	FDRGA0859
051068	66-15311	G	0492	02	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY	0252	ALG-780-370-290	FDRGA0869
111068	66-15294	G	0502	02	FAIL	PRI	NO	SGT1270-1	127	AFT MOUNT DAMPER ASSY		ALG-780-370-290	FDRGA0889
121068	67-15634	G	0101	01	FAIL	PRI	NO	SGT1270-1	674	AFT MOUNT DAMPER ASSY	0101	ALG-381-920-290	FDRNG1763
121068	67-15634	G	0101	01	FAIL	PRI	NO	SGT1270-1	681	AFT MOUNT DAMPER ASSY	0101	ALG-381-920-290	FDRNG1764
301068	67-15495	G	0422	01	FAIL	PRI	YES	SGT1270-1	395	AFT MOUNT DAMPER ASSY	0422	ALG-780-370-290	FDRNG1815
051169	67-15496	G	0442	01	FAIL	PRI	NO	SGT1270-1	406	AFT MOUNT DAMPER ASSY		ALG-381-920-290	FDRNG1835
191169	67-15496	G	0472	01	FAIL	PRI	NO	SGT1270-1	943	AFT MOUNT DAMPER ASSY,L/H		ALG-381-920-290	FDRNG1955
020169	67-15544	G	0337	02	FAIL	PRI	YES	SGT1270-1		AFT MOUNT DAMPER ASSY		ALG-381-920-290	FDRGAA340
040169	66-15333	G	0693	01	FAIL	PRI	YES	SGT1270-1		AFT MOUNT DAMPER ASSY	0228	ALG-381-920-290	FDRGA1382
120169	66-15333	G	0717	01	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY	0252	ALG-381-920-290	FDRGA1402
130169	67-15491	G	0423	01	FAIL	PRI	YES	SGT1270-1	899	AFT.MOUNT DAMPER ASSY	0423	ALG-690-020-290	FDRGC0269
130169	67-15491	G	0423	01	FAIL	PRI	NO	SGT1270-1	392	AFT. MOUNT DAMPER ASSY	0423	ALG-780-370-290	FDRGC0270
210169	66-15268	G	1111	01	FAIL	PRI	YES	SGT1270-1		AFT.MOUNT DAMPER ASSEMBLY		ALG-780-370-290	FDRG21050
030269	67-15497	G	0716	01	FAIL	PRI	NO	SGT1270-1	897	AFT.MOUNT DAMPER ASSY	0525	ALG-690-020-290	FDRGC0385
030269	67-15497	G	0716	01	FAIL	PRI	NO	SGT1270-1	942	AFT. MOUNT DAMPER ASSY	0463	ALG-690-020-290	FDRGC0383
170269	67-15606	G	0549	02	FAIL	PRI	YES	SGT1270-1		AFT MNT DAMPER ASSY		ALG-780-370-290	FDRGA1647
260369	67-15785	G	0211	01	FAIL	PRI	NO	SGT1270-1	1135	L/H AFT MOUNT PYLON DAMP	0211	ALG-690-020-290	FDRGC0714
120569	67-15785	G	0318	01	FAIL	PRI	YES	SGT1270-1	1143	AFT MOUNT DAMPER ASSY R/H	0318	ALG-690-020-290	FDRGC1006
120569	67-15785	G	0318	01	FAIL	PRI	NO	SGT1270-1	1059	AFT MOUNT DAMPER ASSY L/H	0107	ALG-690-020-290	FDRGC1005
290669	67-15545	G	0709	01	FAIL	PRI	NO	SGT1270-1		AFT MOUNT DAMPER ASSY.		ALG-690-020-290	FDRGA2246

Figure 3. Example of failure data computer listing, page a.

BELL HELICOPTER COMPANY
M. AND R. PROGRAM
UH-1 SERIES HELICOPTERS

DESCRIPTION OF FAILURE/DISCREPANCY PAGE NO 122-B
CONCISE FIELD FAILURE/DISCREPANCY REPORT LISTING
PART NUMBER SEQUENCE

PART NUMBER	DESCRIPTION OF FAILURE/DISCREPANCY	CAUSE OF FAILURE/DISCREPANCY	DUP	NOT DUR	MISS ABRT CODE	MTN	PROBLEM FILE NUMBER	REPORT NUMBER
SGT1270-1	EXCESSIVELY WORN(STILL ON A/C)	UNKNOWN		2	H	L	ALG-780-370-290	FDRGB0457
SGT1270-1	SHIMS WORN/FREE MVMNT.EXCESSIVE	UNKNOWN		5	H	P	ALG-780-370-290	FDRGB0484
SGT1270-1	SHIMS WORN/FREE MVMNT.EXCESSIVE	UNKNOWN		5	H	P	ALG-780-370-290	FDRGB0485
SGT1270-1	LEAKING FLUID+HAS EXCESSIVE PLAY	UNKNOWN(A/C HAD SLT.SHUDDER-PULLOUT)		2		Y	ALG-780-370-290	FDRNG1393
SGT1270-1	HEAVY 1-1 VERTICAL VIBRATION IN FLT	GAP IN SPRING SEAT + SPIROLOX EXCESS		2		Y	ALG-780-370-290	EIREG0934
SGT1270-1	WORN-BAD LATERAL VIBRATION	UNKNOWN		2	E	Y	ALG-803-502-290	FDRGA0631
SGT1270-1	A/C VIBRATION/DEFECTIVE PYLON DAMPER	LAMINATED SHIMS WONT STAND LOAD+VIB.	X			Y	ALG-780-370-290	CSOC21950
SGT1270-1	A/C VIBRATION/DEFECTIVE PYLON DAMPER	LAMINATED SHIMS WONT STAND LOAD+VIB.	X			Y	ALG-780-370-290	CSOC21951
SGT1270-1	PYLON ROCK	R/H PYLON DAMPER FAILED INTERNALLY		2		Y	ALG-780-370-290	CSOC21948
SGT1270-1	1-1 VIB,WIDE GAP RET.SPR.ST.-SPIROLX	UNKNOWN,SUS.HARD LANDING		2		Y	ALG-780-370-290	EIREG0918
SGT1270-1	SHIP SHUDDER WHEN PULLING OUT DIVE	L/H PYLON DAMPER LEAKING+EXCESS PLAY	X	2		Y	ALG-780-370-290	CSOC21947
SGT1270-1	LEAKING FLUID (L/H LOCATION)	UNKNOWN/SUSPECT INTERNAL SEAL FAIL.		1	E	Y	ALG-381-920-290	FDRNG1420
SGT1270-1	APPEARED TO BE LEAKING FLUID	UNKNOWN		1	E	R	ALG-381-920-290	FDRGB0577
SGT1270-1	R/H DAMPER LEAKING FLUID	INTERNAL SEAL FAILURE SUSPECTED		2	E	Y	ALG-381-920-290	FDRNG1434
SGT1270-1	LEAKING	UNKNOWN		4	E	C	ALG-381-920-290	FDRGA0617
SGT1270-1	HEAVY 1-1 VERT.VIBRATION IN FLIGHT	WIDE GAP AT SPRILOX,HARD LANDING		2		Y	ALG-690-020-290	EIREG0950
SGT1270-1	HEAVY 1-1 VERT.VIBRATION IN FLIGHT	WIDE GAP AT SPRILOX,HARD LANDING		2		Y	ALG-690-020-290	EIREG0951
SGT1270-1	SEEPING	UNKNOWN-INTERNAL		1	E	Y	ALG-381-920-290	FDRNG1491
SGT1270-1	SEEPING	UNKNOWN-INTERNAL		1	F	Y	ALG-381-920-290	FDRNG1509
SGT1270-1	DAMPERS WORN	UNKNOWN		4	E	Y	ALG-690-020-290	FDRG2 257
SGT1270-1	R/H DAMPER HAS UP-AND-DOWN MOVEMENT	UNKNOWN		1	F	Y	ALG-690-020-290	FDRGG1384
SGT1270-1	L/H XMSN MOUNT DAMPER LEAKING	UNKNOWN		5	E	Y	ALG-381-920-290	FDRGG1499
SGT1270-1	BOTTOMMING OUT + RIVETS SHEARED	RETAINER RING LETS SPRING SLIP	X			Y	ALG-780-370-290	EIREG0827
SGT1270-1	L/H DAMPER MOUNTING LOOSE	BOLT LOOSE/SUSPECT VIBRATION		1	F	N	ALA-730-105-290	FDRG20687
SGT1270-1	SHIP HAS LOPING RIGHT TO LEFT	SUSPECT MALFUNCTION IN AFT DAMPERS		2	E	Y	ALG-690-020-290	FDRGG1546
SGT1270-1	BUMPING + POUNDING VIBRATIONS	DAMPER BOTTOMED OUT-SPRING TEN. LOST	X	2		Y	ALG-780-370-290	EIREG0065
SGT1270-1	L/H DAMPER LOOSING FLUID	SUSPECT INTERNAL SEAL FAILURE		3	E	Y	ALG-381-920-290	FDRNG1663
SGT1270-1	A/C HAS ONE TO ONE VERTICAL	BOTH DAMPERS HAVE PLAY		2	E	Y	ALG-690-020-290	FDRGA0835
SGT1270-1	A/C HAS MODERATE 1-1 VIB.PAST 140KNT	DAMPERS INEFFECTIVE		5	E	R	ALG-780-370-290	FDRGA0859
SGT1270-1	BOTH AFT DAMPER ASSY HAVE END PLAY	LAMINATED SHIMS BEAT OUT		5	F	R	ALG-780-370-290	FDRGA0869
SGT1270-1	BOTH DAMPER ASSY HAVE END PLAY	SHIMS BEAT OUT		5	E	Y	ALG-780-370-290	FDRGA0889
SGT1270-1	DAMPER LEAKING FLUID	SUS.SAND+GRIT CAUSED SEAL FAILURE		5	E	Y	ALG-381-920-290	FDRNG1763
SGT1270-1	DAMPER LEAKING FLUID	SUS.SAND+GRIT CAUSED SEAL FAILURE		5	E	Y	ALG-381-920-290	FDRNG1764
SGT1270-1	1-1 VERTICAL VIBRATIONS	INTERNAL FAILURE OF R/H DAMPER		2	F	Y	ALG-780-370-290	FDRNG1815
SGT1270-1	R/H DAMPER LEAKING	INTERNAL SEAL FAILURE		3	E	Y	ALG-381-920-290	FDRNG1835
SGT1270-1	LEAKING FLUID	UNKNOWN-INTERNAL TO ITEM-SUS.SEAL		3	E	Y	ALG-381-920-290	FDRNG1955
SGT1270-1	A/C HAS 1:1 VERT.XCESS AT HIGH SPEED	UNKNOWN		2	F	R	ALG-381-920-290	FDRGAA340
SGT1270-1	A/C HAS 1:1 VIBRATION	L/H DAMPER LEAKD.HYD.FLUID,BOTTM.OUT		2	E	P	ALG-381-920-290	FDRGA1382
SGT1270-1	AFT L/H DAMPER ASSY.LEAKING FLUID	SPRING LOCKING CLIP FELL OUT		1	E	R	ALG-381-920-290	FDRGA1402
SGT1270-1	PYLON ROCK INITIATED IN HOVER	L/H+R/H PYLON DAMPRS.DETER.BEYND.SER		3	E	Y	ALG-690-020-290	FDRGC0269
SGT1270-1	PYLON ROCK INITIATED IN HOVER	L/H+R/H PYLON DAMPRS.DETER.BEYND.SER		2	E	Y	ALG-780-370-290	FDRGC0270
SGT1270-1	SPIRAL LOCK RING DISPLACED	UNKNOWN		1	H	C	ALG-780-370-290	FDRG21050
SGT1270-1	SLIGHT PYLON ROCK,CONTROLS PULL.LEFT	AFT LEFT DAMPER HAS 18IN PLAY		2	E	Y	ALG-690-020-290	FDRGC0385
SGT1270-1	SLIGHT PYLON ROCK,CONTROLS PULL.LEFT	AFT RIGHT DAMP.SPR.HAS NO TENSION		2	E	Y	ALG-690-020-290	FDRGC0383
SGT1270-1	EXCES.A/C VIBRA.IN TURNS+PULL OUTS	SHIMS BEAT OUT ON DAMPERS		2	E	R	ALG-780-370-290	FDRGA1647
SGT1270-1	SLIGHT PYLON ROCK IN HOVER	INT.FAIL.OF AFT L/H MOUNT PYL.DAMPER		2	E	Y	ALG-690-020-290	FDRGC0714
SGT1270-1	FEEDBACK IN COLL.CONTROLS+PYLON ROCK	SUS AFT PYLON DAMPERS BAD		2	E	Y	ALG-690-020-290	FDRGC1006
SGT1270-1	FEEDBACK IN COLL.CONTROLS+PYLON ROCK	SUS.AFT PYLON DAMPERS BAD		2	F	Y	ALG-690-020-290	FDRGC1005
SGT1270-1	XCESSIVE PYLON ROCK	L/H DAMPER SOFT DUE TO INTERNL.FAIL.		2	E	Y	ALG-690-020-290	FDRGA2246

Figure 4. Example of failure data computer listing, page b.

TABLE 5. BASELINE FAILURE RATE SUMMARY FOR UH-1D*

Subsystem	(1) Total Primary Material Failures	(2) No. of Failures for Components With a Reliability Improvement	(3) No. of Failures for Components Without a Reliability Improvement (1) − (2) = (3)	(4) Subsystem Baseline Failure Rate λ_b (3)/24824
Airframe	572	267	305	.012287
Seats	69	56	13	.000524
Controls	623	321	302	.012166
Drive	137	76	61	.002457
Electrical	34	2	32	.001289
Fuel	24	0	24	.000966
Oil Cooling	72	33	39	.001572
Power Plant	116	23	93	.003746
Rotors	194	106	88	.003545
Caution/Warning	35	21	14	.000564
Total Failure Count	1876	905	971	
Total Aircraft Baseline Failure Rate				.039116

* Based on an analysis of data for 26 selected monitored aircraft and 24,824 flight hours.

TABLE 6. BASELINE FAILURE RATE SUMMARY FOR AH-1G*

Subsystem	(1) Total Primary Material Failures	(2) No. of Failures for Components With a Reliability Improvement	(3) No. of Failures for Components Without a Reliability Improvement (1) - (2) = (3)	(4) Subsystem Baseline Failure Rate λ_b (3)/24824
Airframe	2331	907	1424	.021487
Seats	71	14	57	.000860
Controls	2155	1366	789	.011905
Drive	630	364	266	.004014
Electrical	1888	441	1447	.021834
Fuel	99	0	99	.001494
Hydraulic	306	34	272	.004104
Instrument Installation	128	68	60	.000905
Oil Cooling	289	237	52	.000785
Power Plant	621	154	467	.007047
Rotors	600	27	573	.008646
Caution/ Warning	431	153	278	.004195
Auxiliary Equipment	187	75	112	.001690
Total Failure Count	9736	3840	5896	
Total Aircraft Baseline Failure Rate				.088966

* Based on an analysis of data on 117 monitored aircraft and 66,272 flight hours.

Fiscal Year / Problem Number	1	2	3	4
#1	λ_o	λ_1	λ_1	λ_1
#2	λ_o	λ_o	λ_1	λ_1
#3	λ_o	λ_o	λ_o	λ_1
#4	λ_o	λ_o	λ_o	λ_1
#5	λ_o	λ_o	λ_1	λ_1
Baseline Failure Rate λ_b	λ_b	λ_b	λ_b	λ_b
Total Failure Rate for Each FY $\lambda_T = \Sigma\lambda_o + \Sigma\lambda_1 + \Sigma\lambda_b$	λ_{T1}	λ_{T2}	λ_{T3}	λ_{T4}

where $\lambda_{T1} \geq \lambda_{T2} \geq \lambda_{T3} \geq \lambda_{T4}$ indicating a decreasing failure rate.

Figure 5. Illustration of method for calculating aircraft failure rate by fiscal year.

TABLE 7. UH-1D MTBF GROWTH SUMMARY*

FY	(1) λ_b Failures Common to All FY UH-1D Aircraft	(2) λ of the Components That Are Improved as Applicable to Each FY	(3) λ Total for Each FY Configuration (1) + (2) = (3)	(4) MTBF (Hours) 1/(3)
YUH-1D	NA	NA	.128205*	7.8
62	.039116	.066594	.105710	9.5
63	.039116	.060624	.099740	10.0
64	.039116	.040704	.079820	12.5
65	.039116	.026106	.065222	15.3
66	.039116	.020672	.059788	16.7
67	.039116	.015093	.054209	18.4
68	.039116	.008088	.047204	21.2
69	.039116	.007525	.046641	21.4

* Total failure rate observed on YUH-1D aircraft used to calculate the off-board MTBF (i.e., after 100 test hours).

TABLE 8. AH-1G MTBF GROWTH SUMMARY*

FY	(1) λ_b Failures Common to All AH-1G Aircraft	(2) λ of the Components That Are Improved as Applicable to Each FY	(3) λ Total for Each FY Configuration (1) + (2) = (3)	(4) MTBF ~~Hours~~ 1/(3)
FY 66 Lot 4&5 Off-Bd	NA	NA	.151915*	6.6
FY 66 Lot 6	.088966	.060164	.149130	6.7
67	.088966	.054905	.143871	7.0
68	.088966	.034558	.123524	8.1
69	.088966	.017460	.106426	9.4
70	.088966	.014683	.103649	9.6

* Total failure rate observed on aircraft used to calculate the off-board MTBF (i.e., after 100 test hours).

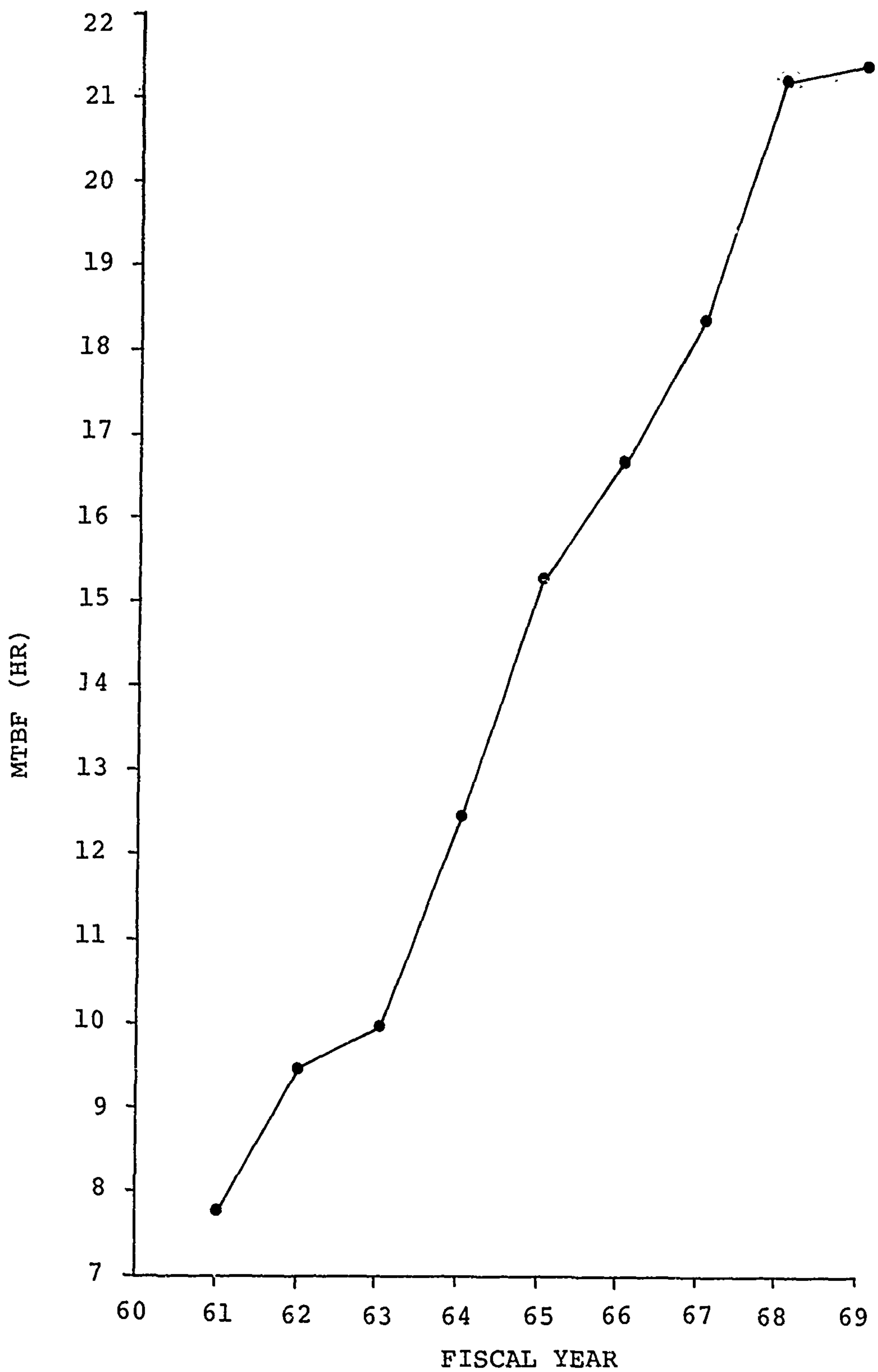

Figure 6. UH-1D reliability (MTBF) versus fiscal year configurations.

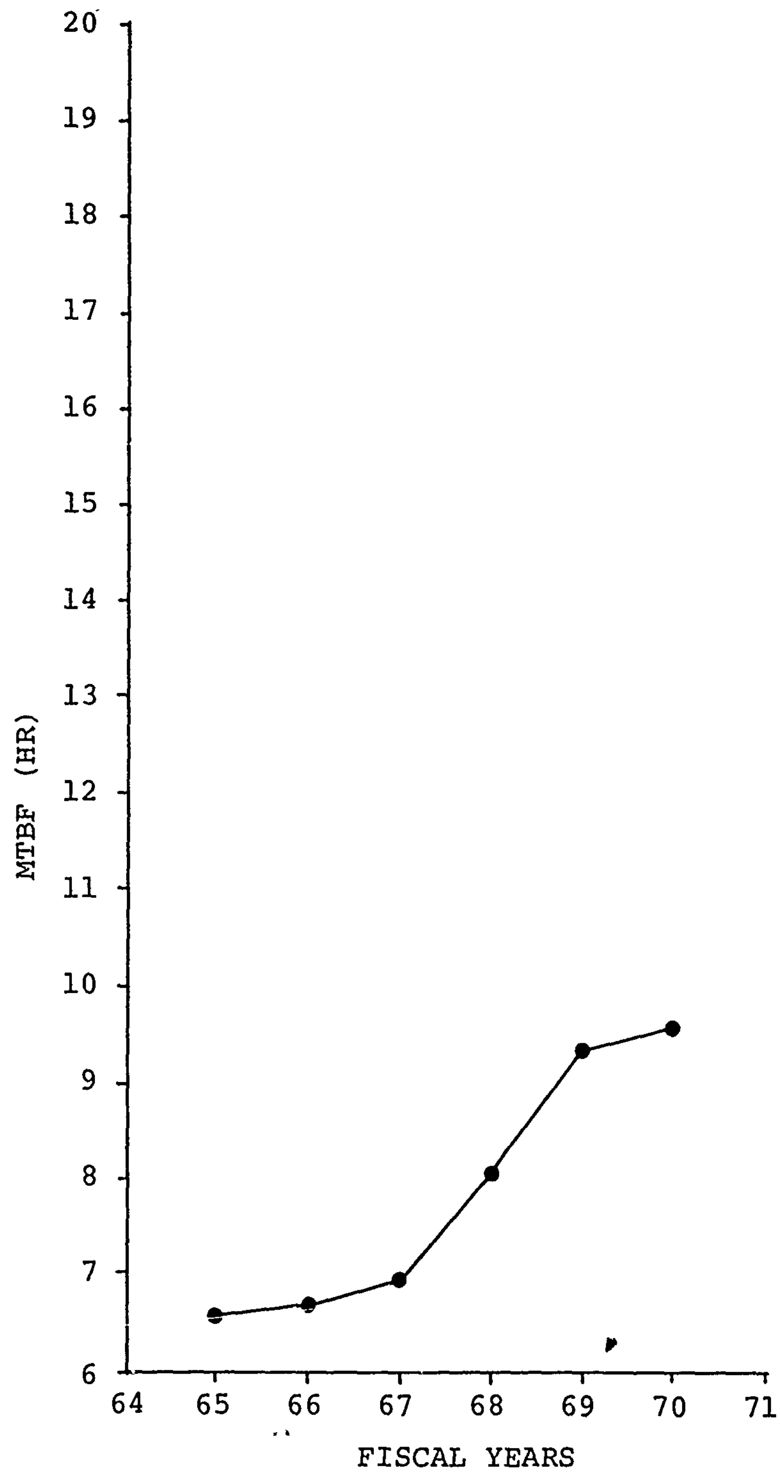

Figure 7. AH-1G reliability (MTBF) versus fiscal year configurations.

3.0 ANALYSIS RESULTS

This section presents reliability growth analysis summaries for the UH-1D and AH-1G helicopters. Their growth histories are compared to each other and to the parameters defined in the RPM technique for reliability growth prediction. Conclusions are presented on the applicability of the RPM technique to helicopter reliability growth.

Beginning with Figure 3, cumulative reliability growth (MTBF) is plotted against cumulative test time (monitored flight hours) on log-log graph paper. The slope of the straight line fitted through these data points is the reliability growth of the helicopter. Each data plot on log-log coordinates resulted in a growth curve with two line segments, each with a distinct slope. This was a result of flight operations' not being stopped on the monitored fleet when a failure occurred. Thousands of additional test hours could accumulate before the aircraft received a hardware change due to that failure. Frequently, long calendar lead time is required to introduce corrective action to the hardware following definition of a problem.

Hardware change effectivities occurring at the beginning of a new production lot (not the beginning of a fiscal year production run) were considered to be incorporated at the beginning of the next fiscal year model production run. This was done because of the difficulty in tracking the numerous design changes by production lots rather than fiscal year model and because it was not feasible to maintain an account of retrofit kit changes for each aircraft versus the time at which the kit was installed for the monitored fleet.

Each log-log plot has an accompanying Cartesian coordinate plot of the same data. No attempt is made to connect the raw data points on the Cartesian plots. However, coordinates of the straight line segments of the corresponding log-log plot are transferred to the Cartesian plot to form a smooth curve. This procedure was used to fair in a smooth line through widely dispersed data points.

Plots of MTBF versus test time have several MTBF values clustered at the highest accumulated test time. This occurs since corrective action activities resulting from the M&R program continued for a period following termination of the monitoring effort.

3.1 UH-1D RELIABILITY GROWTH ANALYSIS SUMMARY

The UH-1D analysis summary includes sensitivity tests to determine the significance of the various parameters affecting reliability growth. Included also are analyses to determine subsystem contributions to the overall aircraft failure rate.

3.1.1 Sensitivity of UH-1D Reliability Growth Curves to Test Hour Variations

The 61 UH-1D problems corrected were identified by the M&R program, and the subsequent corrective actions were substantiated by continued monitoring during that same program. Therefore, the flight time generated by the aircraft monitored during the M&R program was used as the "in-service" test time. This is the test time resulting in slope α_2 in the following discussion.

However, flight-test time other than the M&R program flight time existed during development of the UH-1D. The question is, should it have been a part of the test time for reliability growth? A sensitivity analysis was conducted to determine the effect of this additional test time on plots of reliability growth of the UH-1D. Three combinations of test times were considered. Test times included in each combination are shown by an "X" in the matrix below.

	Test Hour Source				
			BHC UH-1D Test		
Growth Curve Slope	M&R Program	YUH-1D Fleet	All	100 Hrs	280 Hrs
α_1	X	X	X		
α_2	X	2899			X
α_3	X	2899		YUH-1D	X

Growth curve slope α_1 test time is the sum of all BHC/Army M&R program flight time, the entire YUH-1D fleet time, and all of flight test time conducted on the UH-1D at BHC prior to customer delivery. Growth curve slope α_2 test time is the sum of M&R program times, the 2899 hours of YUH-1D fleet time that was accumulated prior to beginning of the M&R program, and 280 hours of BHC prototype test time that occurred prior to the beginning of the M&R program. Growth curve slope α_3 test time is the sum of 100 flight hours of shakedown time on the YUH-1D conducted at BHC, 280 hours of BHC prototype flight-test time prior to production deliveries, and the remaining M&R program time. Table 9 presents the test hours for the above test time combinations and the MTBF's from Table 7, column 4 for each fiscal year aircraft group at the time of their delivery. Using data from Table 9, the growth curves with slopes α_1, α_2, and α_3 are plotted in Figures 8, 10, and 12. Figures 9, 11, and 13 are the corresponding Cartesian plots. Comparison of the slopes of these curves, shown below, indicates that the test hour variations made no substantial difference in the growth curves; i.e., the differences in the growth rates were small. A plot of the curves shown in Figure 14 presents a graphical comparison of the relative slope of each segment.

Test-Hour Combination	Slope, α, of Growth Curve Segment A	B
1	0.065	0.42
2	0.064	0.37
3	0.062	0.33

From the above tabulations, it is seen that there were no significant changes in the growth rates caused by differences in the test hour combinations. It is believed that the test hour combination which resulted in the curve with slope ∂_2 is the most representative since the test hours span the greatest amount of calendar time encompassing all of the major development test programs for the UH-1D. Therefore, for purposes of this study, UH-1D reliability growth log-log plots will consider the curve with slope α_2. The 3179 hours, the sum of 2899 hours of YUH-1D time, 280 hours of BHC test, and 100 hours shakedown, occurred prior to delivery of the first production UH-1D. This time could not be ignored since it was responsible for the MTBF increase from 7.8 hours to 9.5 hours. The remainder of the test hours are from the M&R program.

3.1.2 Sensitivity of UH-1D Reliability Growth Curves to Variation in Number of Problems Corrected

In addition to the 61 UH-1D problems receiving corrective action, there were 15 that had corrective actions proposed which were later rejected by the customer. Had these been approved, the total number of problems receiving corrective action would have been 76 with no increase in the number of test hours. Figure 9 is a plot of the MTBF slope if the additional 15 failure mode rates had been removed from the baseline rate, i.e., the problems had been corrected. The plot was made assuming 100 percent elimination of the failure mode rates so that the most optimistic growth could be shown. Thus, the growth curve with slope α_4 of Figure 15 is the maximum growth rate obtainable for the UH-1D while supported by a monitoring program, assuming other variables are held constant. Figure 16 is the accompanying Cartesian plot for Figure 15. A comparison of α_2 growth curves of Figure 10 and α_4 curves of Figure 15 shows the following slopes:

	Growth Curve Segment	
	A	B
α_2	0.062	0.36
α_4	0.062	0.38

Thus, the α_4 curves do not differ significantly from the α_2 curves, indicating that most of the significant problems were corrected during the monitoring program and that the failure mode rates for the 15 problems were relatively low. Also, the equal segment A slope values indicate none of the 15 problem correction proposals occurred until late in the program, resulting in α_{4B} receiving their full benefit. Since the α_{4B} was not that much greater than the α_{2B} value, it is evident that the maximum growth rate for the UH-1D was being approached. These problems were not corrected due to economic reasons.

3.1.3 Reliability Growth of the Design Versus Reliability Growth of the Hardware - UH-1D

Reliability growth of the helicopter design is a function of accumulation of test hours to the point where a formulated problem corrective action has been approved for incorporation into aircraft hardware. Reliability growth of the hardware is a function of the accumulation of test hours to the point where corrective action has been incorporated as redesigned hardware in production helicopters. Obviously, reliability growth of the design will lead reliability growth of the hardware as long as there is a continuing formulation and approval of corrective actions to be incorporated into hardware. In addition, at any given point in time the reliability of the design will exceed that of the hardware as long as there is a formulated improvement not yet incorporated into the hardware. The UH-1D design MTBF growth versus accumulated test time is tabulated by calendar quarter in Table 10. Figures 17 and 18 are log-log and Cartesian coordinate plots, respectively, of Table 10 data showing the increase in MTBF of the design versus the number of test hours required to initiate the improvement. On Table 10, note that the growth continues for six calendar quarter improvements in the design MTBF following completion of the last test hour (second quarter of 1967 through third quarter of 1968). This demonstrates that there was considerable lag between the occurrence of a failure mode and the formulation and approval of a design change to correct the deficiency. This is in addition to the lead time required to incorporate the design change into hardware. Recall that Figures 10 and 11 are plots of UH-1D demonstrated MTBF versus the number of test hours accumulated to the point where the improvement was actually incorporated into the hardware. Figures 19 and 20 are composite log-log and Cartesian plots, respectively, of growth curves of Figures 10 (α_2) and 11 (α_5) and Figures 11 and 18. Comparing the slope values in Figures 19, α_{5A} is greater than α_{2A}, indicating, as would be expected, that a greater number of design changes were formulated and approved than were incorporated into hardware during early testing. Further, growth curve segment α_{5B} starts several thousand test hours before the corresponding segment α_{2B}; however, the curves tend to converge due to subsidence of design change activity while hardware changes continue.

3.1.4 Subsystem Contribution to UH-1D Helicopter System Reliability Growth

The UH-1D experienced a 56 percent decrease in its failure rate at the system level from FY62 through FY69 production helicopters. Table 11 is a summary of subsystem failure rate decrease by fiscal year production. The airframe, controls, and drive systems accounted for approximately 80 percent of the total decrease through eight fiscal year models. Note, also, that these same subsystems accounted for 80 percent of the total aircraft failure rate at the beginning of FY62, indicating that none had an initial failure rate out of proportion to their share of the total system rate decrease. With the exception of the fuel supply, each subsystem shows some reliability growth. The UH-1D fuel supply subsystem is relatively simple and has few moving parts. No design changes were made to that system. In contrast, the airframe, controls, and drive subsystems proved to be a steady source of design changes, contributing to 80 percent of system level growth. Table 12 presents the subsystem failure rate percentage change by fiscal year. Each subsystem fiscal year failure rate decrease is expressed as a percentage reduction from the failure rate of the previous year and as a percentage contribution to the total aircraft failure rate decrease.

3.2 AH-1G RELIABILITY GROWTH ANALYSIS SUMMARY

The methodology used in creating the AH-1G reliability growth curves follows that used for the UH-1D. Flight test records were not readily usable for extracting the type information required for reliability growth analysis. Also, due to the urgency of the Vietnam war, the AH-1G was put into high-volume production without any YAH-1G development aircraft being procured. This resulted in the absence of development test data similar to that generated by the YUH-1D fleet. Thus, all data used in plotting growth curves in this section are from the M&R program.

Table 13 presents the time base used to plot observed MTBF versus test time for the AH-1G. The MTBF values are those for the FY aircraft at the time of their entry into service. Since there were no YAH-1G aircraft produced, an off-board MTBF value was established using M&R monitored data from FY66 lots 4 and 5. The value was established from failures occurring with the first 100 hours of operation. This was determined from failure monitoring of two of the initial production group of 34 AH-1G aircraft. The remaining FY66 AH-1G production contained 74 aircraft. Figures 21 and 22 are the log-log and Cartesian plots, respectively, of Table 13 data.

3.2.1 AH-1G Reliability Growth Curve Sensitivity to Variation in Number of Problems Corrected

There were 95 problems on the AH-1G for which corrective action was recommended under the M&R program. Three were rejected by the customer. Table 13 shows a slight improvement in MTBF, had all the corrective action recommendations been incorporated. Log-log and Cartesian plots of the data are presented in Figures 23 and 24, respectively. Table 13 data and Figures 23 and 24 assume 100 percent elimination of the failure mode rate. A comparison of the growth curve α values of Figures 21 and 23 is presented below:

	Growth Curve Segment	
	A	B
α_6	0.016	0.099
α_7	0.016	0.123

As occurred with the UH-1D, there was little improvement in slope due to removal of unincorporated improvements from the baseline. Table 13 data indicate that the final FY70 MTBF would have increased only from 9.6 to 9.9 hours. These data indicate that the AH-1G achieved close to its maximum rate of growth supported by the monitoring program.

3.2.2 Reliability Growth of the Design Versus Reliability Growth of the Hardware - AH-1G

The AH-1G design MTBF growth versus accumulated test time is tabulated by calendar quarter in Table 14. The accounting of design changes and test time by calendar quarter provides a common denominator for determining a relationship between test hours and MTBF growth of the design. Figures 25 and 26 are log-log and Cartesian coordinate plots, respectively, of Table 14 data. The α_8 of Figure 25 growth curve reflects only two calendar quarter improvements in the design MTBF as a result of the M&R program, following completion of the last test hour. Considering that the UH-1D had six calendar quarters, apparently less lead time was required to get design changes into hardware for the AH-1G than for the UH-1D. This is a function of the higher AH-1G program intensity and, to some extent, the factors in the AH-1G program termination. Further evidence of the effects of increased program intensity is seen in Figure 27, a composite of the α_6 (hardware growth) curves of Figure 21 and the α_8 (design growth) curves of Figure 25, and in Figure 28, a composite of the Cartesian coordinate plots of Figures 22 and 26. At any given point on the test hour scale, there is only a small difference between points on the design and hardware growth curves.

3.2.3 Subsystem Contribution to AH-1G Helicopter System Reliability Growth

The AH-1G failure rate decreased 31.8 percent over five FY aircraft models. Table 15 presents a subsystem failure rate decrease summary for the AH-1G, including the relative contribution of each subsystem to the overall failure rate decrease. Each subsystem with the exception of fuel supply had some reliability growth. Like the UH-1D, the AH-1G fuel supply subsystem is simple and has few moving parts. Its FY66 failure rate represented less than 1 percent of the total aircraft failure rate; thus, any further improvements would have little statistical influence on reliability growth. Airframe, controls, and electrical subsystems provided the bulk of reliability growth, approximately 72 percent of the total decrease in failure rate. It would not be correct to identify these three systems as being the most in need of reliability improvement since their size, nature, and complexity govern individual contribution to the total failure rate. Table 16 compares each subsystem percentage of original aircraft failure rate (Column A) to percentage contribution to total decrease in failure rate (Column B). In Column C, the ratio B/A is a measurement of a subsystem's contribution to total improvement without regard to other factors. A ratio value greater than one indicates a proportionately greater contribution. The oil cooling and controls subsystems had the greatest proportionate decrease in failure rate, while the fuel subsystem had the least. Table 17 presents the subsystem failure rate percentage change by fiscal year. Each subsystem fiscal year failure rate decrease is expressed as a percentage reduction from the failure rate of the previous year and as a percentage contribution to the total aircraft failure rate decrease.

3.3 UH-1D RELIABILITY GROWTH VERSUS AH-1G RELIABILITY GROWTH

The reliability growths of the UH-1D and AH-1G are compared in this section. Points of similarity and difference are examined to determine the factors that control the rate of reliability growth.

3.3.1 Comparison of UH-1D and AH-1G Reliability Growth - Log-Log Curves

The analysis methods and procedures used in this study permit normalization of the data. This was done to allow better comparison of the reliability growth of the UH-1D and AH-1G helicopters. However, that process was at best limited. There are factors that challenge the results in this study. Consider Figure 29, a composite log-log plot of the UH-1D growth curve α_2 and the AH-1G growth curve α_6. Obviously, from the plot, the UH-1D had a much higher rate of reliability growth than did the AH-1G, at least when MTBF increase was plotted against cumulative test time on log-log paper. This would appear to be a contradiction, knowing that the AH-1G M&R program intensity was greater than that for the UH-1D. AH-1G program data covered 66,000 flight hours of monitored time accumulated in 29 calendar months, producing problem corrections at the rate of 3.17 per month or one problem correction for each 730 flight hours; while the UH-1D data base of 50,000 monitored flight hours was accumulated in 39 calendar months, producing problem correction at the rate of 1.56 per month or one correction for each 820 flight hours. Thus, the AH-1G problem correction rate was double that of the UH-1D. Ultimately, the AH-1G M&R program produced 50 percent more problem corrections than did the UH-1D M&R program. Figure 30 shows the number of problem corrections by FY configuration for both aircraft models. Figure 31 presents cumulative corrections versus FY configuration for both aircraft models. These facts and figures raise questions as to the validity of Figure 29 plots. Figure 31 reflects the true impact of program intensity and may well be the only legitimate measure of program intensity for helicopters. Also, it is apparent that reliability growth is not a function of the number of corrective actions accomplished. The 61 corrective actions for the UH-1D resulted in an aircraft failure rate reduction of 0.059069 over eight fiscal years, or 0.000968 average for each corrective action. In comparison, the 92 corrective actions for the AH-1G resulted in an aircraft failure rate reduction of 0.048267 over five fiscal years or 0.000530 average for each corrective action taken. Thus, a smaller number of corrective actions on the UH-1D produced a proportionately greater return in failure rate reduction as compared to those of the AH-1G program.

3.3.2 A Variation in Approach to Reliability Growth Measurement of the AH-1G and UH-1D

The disparity between UH-1D and AH-1G growth (MTBF) when plotted on log-log paper requires additional examination. The main factor, increased program intensity, used to accelerate reliability growth for the AH-1G was not reflected in Figure 29. Specifically, the high-intensity AH-1G program should have shown an increase in the growth rate over that of the UH-1D medium-intensity program. It was assumed that an increase in program intensity would cause an increase in the number of problems corrected. This assumption was valid. It was also assumed that the increase in the number of problems corrected would mean a proportionate decrease in failure rate. This assumption was not valid, as was demonstrated in the preceding section. Further, when compared to the UH-1D, any improvements in MTBF on the AH-1G were offset when plotted against the AH-1G's large accrued test time. The improvements in MTBF were a result of accelerated rate of problem correction which, in turn, was some function of the accelerated testing (monitored flight hours). The only parameter that could not be affected by the accelerated program was calendar time. The AH-1G did, in fact, attain a higher rate of reliability growth than did the UH-1D. This is demonstrated in Figure 32, a plot of AH-1G and UH-1D cumulative decrease in failure rate versus calendar months following first aircraft model delivery. Figure 33 presents cumulative decrease in failure rate attained by progressive fiscal year aircraft through the end of the M&R program. These two figures allow comparison as if both M&R programs had been conducted simultaneously. Both illustrate the higher growth rate of the AH-1G. Tables 18 and 19 show for the UH-1D and AH-1G, respectively, subsystem failure rate cumulative percentage change at each fiscal year following first aircraft delivery. By the fourth FY delivery, the UH-1D (FY66) had a 35.4 percent cumulative reduction in its failure rate, while the AH-1G (FY70) experienced a 31.8 percent reduction in its total failure rate. When measured in this manner, the growth rates of the two aircraft are almost equal. A composite plot of these data is presented in Figure 34. The pattern of failure rate reductions for both aircraft is very similar, as was shown in Figures 32 and 33. The Figure 34 plot negated the effect of the 44-percent failure rate spread between the UH-1D and the AH-1G. In doing so, evidence is created that program intensity may not be a factor with enough influence to redirect the reliability growth of a helicopter.

Program intensity strongly affects the rate of problem correction, but for helicopters it has little effect on failure rate reduction. While each problem correction does contribute to failure rate reduction, that change in failure rate may have a wide range of values. This is shown in Figure 35. The M&R program identified a large number of problems that were candidates for corrective action. There existed no direct relationship between the magnitude of the failure rates and the order in which the problems were corrected. However, as is also shown in Figure 35, the AH-1G program did correct many more low failure rate problems than did the UH-1D. The effects on crew safety, aircraft availability, mission success, ease of repair, and economic cost generally led the factors governing when or whether a problem was corrected. There was a situation in the M&R program where the single occurrence of a failure mode resulted in a design change. Conversely, there were many situations where high failure rate problems were not corrected. These are extreme cases. However, they serve to demonstrate the nonexistence of a relationship between failure rate magnitude and initiation of corrective action.

3.3.3 Statistical Observations on UH-1D and AH-1G Reliability Growth

This section provides two theoretical models which relate reliability growth to calendar time on the basis of monitoring programs for the UH-1D and AH-1G. It should be noted that the number of flying hours of the respective monitoring programs per calendar year is large. Consequently, the relationships developed here for reliability growth and calendar time presuppose a large number of flying hours per calendar year. The models can be applied in a new program to project reliability growth beyond the end of the monitoring period.

In this analysis, the decrease in failure rate (i.e., reliability growth) as a function of reliability growth time, T, from the plot in Figure 34 is

$$\lambda(T) = \Lambda(T) \{1 - M(T)T\} \tag{1}$$

where $\lambda(T)$ = the failure rate at growth time, T

$\Lambda(T)$ = the failure rate due to all pertinent failures in the aircraft history

$M(T)$ = the decrease in $\Lambda(T)$ per year

An empirical consequence of the analysis is that

$$M(T_i - T_{i-1}) = \frac{\Lambda(T_i - T_{i-1})}{\Lambda(T)}$$

is a constant when $T_i - T_{i-1}$ is considered in increments of years.

Figure 34 suggests that there might exist the same linear relationship between reliability growth time, T, and the cumulative percentage decrease in failure rate for each of the monitoring programs. In order to show the similarity in results, the data from Tables 18 and 19 were subjected to a least-squares fit of a straight line passing through the origin. The estimator of the slope in this method for K data points is given by

$$M = \sum_{i=1}^{K} x_i y_i \Big/ \sum_{i=1}^{K} x_i^2 \tag{2}$$

where x_i is the ith year and y_i is the observed value (i.e., actual percentage reduction in $\Lambda(T)$) for the model. The results were as follows:

$$\hat{M}_{AH-1G} = 8.663333$$

$$\hat{M}_{UH-1D} = 8.613571$$

Consequently, the least-squares fit of the data to a straight line provides a reasonable representation of the relationship between reliability growth time and the cumulative percentage decrease in failure rate for the two aircraft under their respective monitoring programs.

The similarity of slopes over different time bases in programs with different intensity for different aircraft suggests that M(T) is a constant. The reason may be the similarity of the two programs. The following observations of program similarity were made:

- The same reporting forms and analysis procedures were used.

- Data analysis was conducted by essentially the same group of people.

- Corrective action was sought by the same engineering personnel.

- Both programs were managed by the same AVSCOM personnel.

Further, everyone involved went through a learning period on the UH-1D program. Techniques and procedures mastered on the UH-1D program were carried over and applied to the AH-1G program (even though application rate may have increased).

Another point of interest is that the period of monitoring has a carryover time for reliability growth. In the AH-1G, three years of monitoring corresponded to five years of reliability growth. With the UH-1D, five years of monitoring corresponded to eight years of reliability growth. These numbers correlate to consecutive values from the Fibonacci sequence* generated by 1 and 1. In any Fibonacci sequence, the limit of the ratio of consecutive terms has been found to be $\frac{1+\sqrt{5}}{2}$.

Further, since the sequence is quite well behaved, monitoring times which do not appear in the sequence can be used to find reliability growth times by multiplying the monitoring time by $\frac{1+\sqrt{5}}{2}$.

---

*The Fibonacci sequence is the sequence whereby a number in the sequence is the sum of the previous two numbers in the sequence, i.e., $S_k = S_{k-1} + S_{k-2}$. For this problem the Fibonacci sequence is initiated by $S_1 = 1$ and $S_2 = 1$.

In most reliability tests, a minimum acceptable MTBF (or maximum allowable failure rate, λ_o) is specified along with a test time of a specified number of hours within a span of a specified number of calendar months to find the reliability growth time, T_o, as specified previously. Incorporating these values into Equation (1), we have

$$\lambda_o \geqslant \Lambda(T_o) \quad 1 - M(T_o)T_o \tag{3}$$

Therefore,

$$\Lambda(T_o) \leqslant \frac{\lambda_o}{\left\{1 - M(T_o)T_o\right\}} \tag{4}$$

Hence, an upper bound can be found on the entire history of the aircraft failure rate.

For 2-, 3-, and 4-year monitoring programs, find the upper bound on $\Lambda(T_o)$ for minimum acceptable MTBF's of 6 and 10 hours. From the Fibonacci sequence, the monitoring times correspond to 3, 5, and 6.47 years of reliability growth time.

Monitoring time = 2 years

$$\Lambda(3) \leqslant \frac{1/6}{1 - (.086)3} = .224618, \text{ MTBF} = 6 \text{ hours}$$

$$\Lambda(3) \leqslant \frac{1/10}{1 - (.086)3} = .134770, \text{ MTBF} = 10 \text{ hours}$$

Monitoring time = 3 years

$$\Lambda(5) \leqslant \frac{1/6}{1 - (.086)5} = .292397, \text{ MTBF} = 6 \text{ hours}$$

$$\Lambda(5) \leqslant \frac{1/10}{1 - (.086)5} = .175438, \text{ MTBF} = 10 \text{ hours}$$

Monitoring time = 4 years

$$\Lambda(6.47) \leq \frac{1/6}{1 - (.086)(6.47)} = .375730,\ \text{MTBF} = 6 \text{ hours}$$

$$\Lambda(6.47) \leq \frac{1/10}{1 - (.086)(6.47)} = .225438,\ \text{MTBF} = 10 \text{ hours}$$

The result of this analysis, for example, reveals that in conducting a 2-year test to demonstrate an MTBF of 6 hours, the measured MTBF need only be 4.45 hours. Engineering corrective action has demonstrated in previous programs that the reliability growth capability will be sufficient to provide a 6-hour MTBF. This approach provides a rational alternative to the traditional reliability qualification test. Incorporation of reliability growth would assist in narrowing the gap between measured and demonstrated MTBF.

The ability to transfer the concepts found in the AH-1G and UH-1D monitoring programs to other monitoring programs lies in one's ability to establish the value of M.

It is now obvious that, in order to reproduce M as a function of the many variables of which it is composed, a simulation is required. For instance, graphs of corrective action approval as a function of use rate will almost certainly be given in a function which is not continuous. The number of variables and the characteristics of these variables make a reconstruction of M almost impossible without simulation.

It is known that as calendar time increases, $\lambda(t)$ will become asymptotic with a decreasing baseline failure rate. This concept is not reflected in the results stated in Equation (1). Further, for small values of x,

$$1 - x \cong e^{-x}$$

Consequently, $1 - M(T)T$ could be an approximation for $e^{-M(T)T}$. This value would account for an asymptotic behavior and still be consistent with the experience of the monitoring programs under consideration. Thus, Equation (1) would become

$$\lambda(T) = \Lambda(T)e^{-M(T)T} \tag{5}$$

Therefore,

$$\ln\left(\frac{\Lambda(T)}{\lambda(T)}\right) = M(T)T$$

$$\mathrm{lN}\left(\left[\frac{\Lambda(T)}{\lambda(T)}\right]^{1/T}\right) = M(T)$$

Putting these expressions in the framework of minimum acceptable MTBF's, the expression becomes

$$\lambda_o \geqslant \Lambda(T_o)e^{-M(T_o)T_o} \tag{6}$$

$$\Lambda(T_o) \leqslant (\lambda_o)e^{+M(T_o)T_o} \tag{7}$$

For 2-, 3-, and 4-year monitoring programs, find the upper bound on $\Lambda(T_o)$ for minimum allowable MTBF's of 6 and 10 hours. From the Fibonacci sequence, the monitoring times correspond to 3, 5, and 6.47 years of reliability growth time.

Monitoring time = 2 years

$$\Lambda(3) \quad \frac{1}{6}e^{+(.086)3} = .21615, \text{ MTBF} = 6 \text{ hours}$$

$$\Lambda(3) \quad \frac{1}{10}e^{+(.086)3} = .12969, \text{ MTBF} = 10 \text{ hours}$$

Monitoring time = 3 years

$$\Lambda(5) \quad \frac{1}{6}e^{+(.086)5} = .25622, \text{ MTBF} = 6 \text{ hours}$$

$$\Lambda(5) \quad \frac{1}{10}e^{+(.086)5} = .15373, \text{ MTBF} = 10 \text{ hours}$$

Monitoring time = 4 years

$$\Lambda(6.47) \leqslant \frac{1}{6}e^{+(.086)(6.47)} = .29178, \text{ MTBF} = 6 \text{ hours}$$

$$\Lambda(6.47) \leq \frac{1}{10} e^{+(.086)(6.47)} = .17507, \text{ MTBF} = 10 \text{ hours}$$

The results in this analysis are more conservative than in the linear approach. In order to support a 6-hour MTBF in a 2-year monitoring program under this approach, the measured MTBF must exceed an MTBF of 4.62 hours. The minimum acceptable measured MTBF is different under the two approaches. However, as calendar time increases (i.e., length of monitoring program increases), the disparity in the values becomes larger. The asymptotic properties of the second approach coupled with its conservative estimates tend to make it the more viable of the two approaches.

Further, since only two similar aircraft have been considered, extending these models to helicopters in general is risky. In order to validate the theoretical models, further study should be made on diverse aircraft, from different facilities under a variety of monitoring programs. It may, indeed, be that helicopters of the same size (designed and manufactured by the same company and maintained by the same personnel, facilities, and operational structure) will have similar failure rate decreases per calendar year. It could very well be true that the length of time necessary to incorporate corrective action is so excessive that it dominates all other variables involved.

3.3.4 Corrective Action Considerations That Influenced UH-1D and AH-1G Reliability Growth.

The higher intensity AH-1G program did accelerate the rate of failure mode identification, as evidenced by the 283 AH-1G M&R index problems versus 133 for the UH-1D. Also, the rate of corrective action initiation was accelerated: 92 for the AH-1G versus 61 for the UH-1D. There was no hard set of ground rules governing any corrective action taken to eliminate an identified failure mode. However, the following considerations were given to each candidate for corrective action:

- The criticality of the failure mode. Will it endanger the crew, the aircraft, or the mission?
- The effect on availability of the aircraft. Does it require long periods in maintenance for repair actions?
- Logistics cost. What is the cost of repair parts, and what is the effort to maintain them in the logistics pipeline?

- Lead time. Can a satisfactory change be implemented in a reasonable amount of time?

- Maintenance cost. What is man-hour cost to correct each failure?

- Failure mode rate. How often does the failure mode occur in a given number of flight hours?

- Maintenance frequency. What is the unscheduled maintenance action frequency caused by the failure?

- Ease of problem correction. How involved is the correction action? Is the technology available?

- Nuisance factor of the failure mode. How bothersome is it to maintenance and flight crews?

One may conclude that the magnitude of the failure rate of a of the failure modes had limited impact on whether they received corrective action or not and that identification of a failure mode does not necessarily mean that corrective actio will follow.

3.3.5 Impact of Increased Testing Rate on Helicopter Reliability Growth

It is generally assumed that the rate of reliability testing is one of the uncontestable parameters affecting rate of reliability growth. For the UH-1D and AH-1G helicopter, thi has been demonstrated to be untrue. Certainly, beginning wi a low rate, incremental increases in the testing rate will have corresponding incremental increases in the rate of reliability growth. However, at some point for the UH-1D an AH-1G, it appears that the law of diminishing returns sets i and, eventually, a point is reached where any subsequent increase in the test rate will produce no increase in reliability growth. Testing is required to reveal failure modes and for subsequent initiation of corrective actions which, i turn, lead to reliability growth. It has been shown for the helicopters that an increase in the testing rate will increa the rate that failure modes are revealed. Further, it has been shown (Section 3.3.2) that an approximate doubling of t testing rate, 2285 flight hours per month for the AH-1G vers 1280 flight hours per month for the UH-1D, resulted in an approximate doubling of the rate of corrective action initia tion: 3.17 corrections per month for the AH-1G versus 1.56 corrections per month for the UH-1D. However, it has not be established that an increase in the number of corrective actions will be followed by an increase in the rate of reliability growth. Refer to Figure 34, a plot of percentage decrease in failure rate versus FY UH-1D and AH-1G aircraft. When the data points for each helicopter are submitted to a least-squares fit (Section 3.3.3), one finds that the slopes are equal. Yet, the testing rate of the AH-1G was 1005 flight hours per month greather than that of the UH-1D. This suggests that both aircraft have exceeded some ceiling of reliability testing beyond which any increase in the rate will cause no increase in reliability growth. Also, it is believed that there exists a level of testing threshold below which the rate of reliability growth is zero. Below this point the rate of test hour accumulation is so low that failure modes cannot be exposed. Although there are no beginning and intermediate data points to plot the exact curves, it is believed that Figure 36 is a fair representation of the relationship that exists between an increasing testing rate and reliability growth. The significance of this relationship is that the testing rate of the AH-1G exceeded the overall M&R program's ability to produce a proportionate reduction in failure rate. It is probable that the same occurred for the UH-1D. It is believed that the optimum rate of testing for these two aircraft would have been in the 900 to 1100 flight-hours-per-month range. However, a specific test would be required to determine the exact bounds of the interval. This is a point to consider when reliability tests are scheduled in future programs.

3.3.6 UH-1D and AH-1G Reliability Growth Versus Fleet Time

Reliability growth versus fleet time for these aircraft was investigated. Figure 37 presents a plot of the UH-1D and AH-1G MTBF increase versus accrued fleet time. Note that the initial MTBF growth for the UH-1D was considerably greater compared to that of the AH-1G. The fleet time accrual rate of the UH-1D was quite low during its early production years compared to the AH-1G. When the AH-1G entered service during the height of the Vietnam war, the use rate for both aircraft was at its peak. Figure 38 presents a comparison of fleet time accrual. Thus, initial MTBF increases due to corrective actions on the UH-1D were plotted against relatively small amounts of accrued test time compared to that of the AH-1G. This resulted in initially higher growth rate of the UH-1D.

3.4 THE RPM TECHNIQUE COMPARED TO UH-1D AND AH-1G RELIABILITY GROWTH EXPERIENCE

This section examines the UH-1D and AH-1G reliability growth experience in relation to the growth parameters defined in General Electric's reliability growth prediction technique.

This technique, which has been proven acceptable for electronic equipment, is not acceptable for projecting helicopter reliability growth. The factors involving this conclusion are also explored.

3.4.1 A Review of the RPM Technique

The RPM technique is a mathematical approach devised to predict the reliability growth of complex electronic weapon systems. Its development, according to its authors, was i: specific response to the "reliability program credibility ga o that exists between stated equipment reliability requirements and realized or realizable achievement."

It assumes that equipment off-board MTBF will be 10 percent of the MTBF goal. The goal is established by increasing the requirement by 25 percent. It asserts that reliability growth is approximately inversely proportional to the square root of the test time, and that the slope of the curve plotted on a log-log scale varies between $\alpha = 0.1$ for a development program having no formal reliability effort and $\alpha = 0.5$ for an aggressive reliability program.

3.4.2 RPM Technique Compared to UH-1D Reliability Growth Experience

The observed UH-1D reliability growth did not conform to the growth parameters of the RPM technique. The UH-1D off-board MTBF was significantly greater than 10 percent of the mature design MTBF. The actual value, 7.8 hours, was 36 percent of the MTBF ultimately observed. The maximum MTBF experienced for the UH-1D was 21.4 hours. It is doubtful that the MTBF of the UH-1D will ever increase beyond 30 hours, much less by a factor of 10 to 78 hours. Had 30 hours been the MTBF requirement and the goal established at 37.5 hours (1.25 x 30) per RPM, the 7.8-hour off-board value would be 21 percent of this, more than double the 10 percent stated by RPM. This is shown in the table below.

Parameter	Observed Reliability Growth History	RPM Projected Reliability Growth History
Offboard MTBF	7.8 hr	3.75 hr*
Reliability Growth Rate	$\alpha_{2A} = 0.062$	$.4 \geq \alpha \geq .2$**
	$\alpha_{2B} = 0.359$	

*Based on a mature MTBF of 30 hr 10% x (1.25 x 30) = 3.75
**Based on a reliability program of moderate intensity

For the UH-1D, two distinct growth rates were observed on the log-log plots. The RPM prediction procedure does not consider a change in slope. The initial UH-1D slope $\alpha_{2A} = 0.062$ is considerably less than the minimum RPM value, $\alpha = 0.1$ (the growth rate for those programs where no specific consideration is given to reliability). However, $\alpha_{2B} = 0.359$ does fall within the bounds of RPM.

3.4.3 RPM Prediction Technique Compared to AH-1G Reliability Growth Experience

The AH-1G reliability growth was not within the RPM parameters. As was the case with the UH-1D, the off-board MTBF was significantly higher than 10 percent of the MTBF ultimately observed. The AH-1G M&R program was two calendar years shorter in duration than the UH-1D program. However, as implied in paragraph 3.3.3, the AH-1G failure rate would have been reduced approximately 56 percent had its program been of the same duration as that of the UH-1D. The AH-1G would then have had an ultimately observed MTBF of 11.8 hours. It is doubtful that the AH-1G will ever achieve an MTBF above 17 hours, a value significantly lower than 66 hours, ten times the off-board value. Had 17 hours been the MTBF requirement and the goal established at 21.25 hours (1.25 x 17) per RPM, the 6.6-hour off-board value would be 31 percent of this, more than triple the prescribed 10 percent. This is shown in the table below.

Parameter	Observed Reliability Growth History	RPM Projected Reliability Growth History
Offboard MTBF	6.6 hr	2.125 hr*
Reliability Growth Rate	$\alpha_{6A} = 0.016$ $\alpha_{6B} = 0.099$	$\alpha = 0.50$**

*Based on a mature MTBF of 17 hr 10% x (1.25 x 17) = 2.25
**Based on a reliability program of high intensity

Like the UH-1D, two distinct growth rates were observed for the AH-1G on the log-log plots. The initial slope $\alpha_{6A} = 0.016$ was again considerably less than the minimum RPM value ($\alpha = 0.1$). Unlike the UH-1D, the second AH-1G growth curve segment $\alpha_{6B} = 0.099$ remained below the minimum RPM value, even though the AH-1G M&R program was considered to be of greater intensity than that of the UH-1D. This is discussed in subsequent paragraphs.

3.4.4 The RPM Off-Board MTBF Versus Helicopter Off-Board MTBF

The RPM definition of off-board MTBF is, by the nature of the hardware, not that used in the UH-1D and AH-1G growth curve development. The RPM definition is based on taking a statistically derived 10 percent of the MTBF goal. Because of this, many of the low MTBF failure modes are still present prior to the start of system-level testing. Helicopter off-board MTBF is based on "flight quality" hardware. The helicopter components have already experienced design support and quality conformance testing before being pronounced flightworthy. Many of the infant mortality failure modes have been eliminated prior to first flight. Also, helicopter components tend to be part of a continuing growth from model to model. This results in a high off-board MTBF value. Thus, the requirement for "flight quality" hardware for testing ensures that off-board MTBF values will be high.

3.4.5 RPM Program Intensity Parameter Applied to UH-1D and AH-1G Reliability Growth

The particularly noteworthy feature of the RPM technique when applied to complex electronics equipment is that the rate of reliability growth can be substantially altered as a direct function of reliability program intensity. However, when applied to UH-1D and AH-1G helicopters, this was not found to be true. The AH-1G, although developed within a reliability program of higher intensity than that of the UH-1D, demonstrated a lower rate of reliability growth when MTBF increase was plotted against accumulated test time using the RPM technique. See paragraph 3.3.2. For this particular situation, any kind of plot with test time as one of the axes would have the same outcome. Figure 39 further illustrates this. At the upper end of each growth curve there are two or more percentage data points marking the last hour of testing. These points represent the continued reliability growth after completion of the last hour of testing. It also demonstrates that corrective actions indeed do require considerable lead times for incorporation since each data point corresponds to the beginning of a new FY production. The RPM technique applied to avionics testing does not encounter the above circumstances because it requires that failure modes be corrected and a design change be incorporated in the hardware before testing resumes. This is an unrealistic requirement for a helicopter development test program. Aircraft design corrections are time consuming even for the most minute changes. It is not reasonable to require that testing be delayed for incorporation of each design change. If this were to occur, the cost due to down time between test sequences would be unreasonable.

3.4.6 Conclusions on Applicability of RPM Technique for Predicting Reliability Growth of Helicopters

The RPM technique is not a viable method of predicting reliability growth of a helicopter. The preceding paragraphs have shown that the off-board MTBF and ultimate MTBF relationship defined by RPM is not valid for helicopters. RPM does not consider double-segment growth curves. Reliability growth measurement defined by RPM is not suitable for helicopters. When program intensity is changed to alter the growth rate, the response has not been predictable when measured using RPM ground rules. Further, the range of $\alpha = 0.1$ to 0.5 is the result of long study of avionics equipment history. The α values generated by this study have not generally fallen within the bounds of the RPM method.

TABLE 9. FLIGHT (TEST) TIME VERSUS MTBF FOR UH-1D

FY	Accum. Time Bases BHC/Army M&R Program	YUH-1D Fleet	BHC Test	Total Operating Test Time Used To Plot α α_1 Time *	α_2 Time *	α_3 Time *	***** MTBF (Hr)	**** MTBF (Hr)
Col. 1	2	3	4					
** YUH-1D Off-Bd			100	100	100	100	** 7.8	** 7.8
62***	0	2899	280	3179	3179	3179	9.5	9.5
63	0	3932	335	4267	3179	4212	10.0	10.[illegible]
64	13606	5855	435	19896	16785	13886	12.5	12.5
65	21946	6826	485	29257	25125	29052	15.3	15.4
66	36785	7106	535	44426	39964	44171	16.7	16.[illegible]
67	49947	8113	535	58595	53126	58340	18.4	20.[illegible]
68	49947	8453	535	58935	53126	58680	21.2	22.[illegible]
69	49947	8826	535	59308	53126	59053	21.4	27.[illegible]

* α_1 = Col. 2 + 3 + 4

α_2 = Col. 2 + 3179***

α_3 = Col. 4 for YUH-1D, Col. 3 = 4 for FY 62 and Col. 2 + 3 + 280*** for FY 63 through FY 69

** 100 hours shakedown is the earliest point at which off-board can be considered. Prior to 100 hours it is not known what the aircraft MTBF is. The 7.8-hour MTBF was demonstrated on the YUH-1D.

*** 3179 hours includes 100 hours shakedown. 3179 total operating test hours were accomplished prior to the M&R Program beginning and delivery of FY 62 aircraft.

**** Resultant MTBF's if failure rates for unincorporated corrections had been subtracted completely.

***** From Table 7, Col. 4.

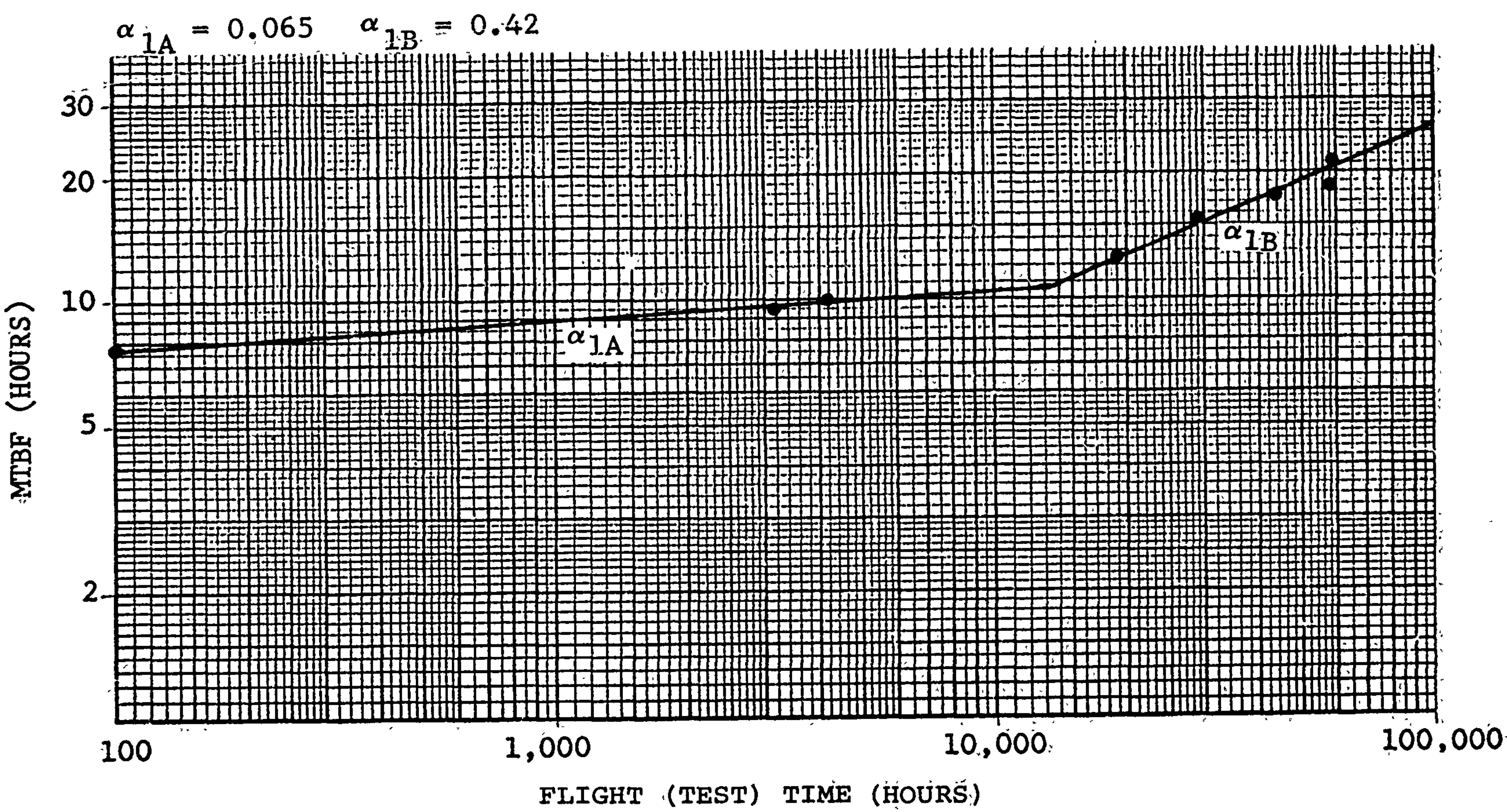

Figure 8. Reliability growth (MTBF) for UH-1D versus flight time (M&R Program monitored time, YUH-1D time and BHC test time).

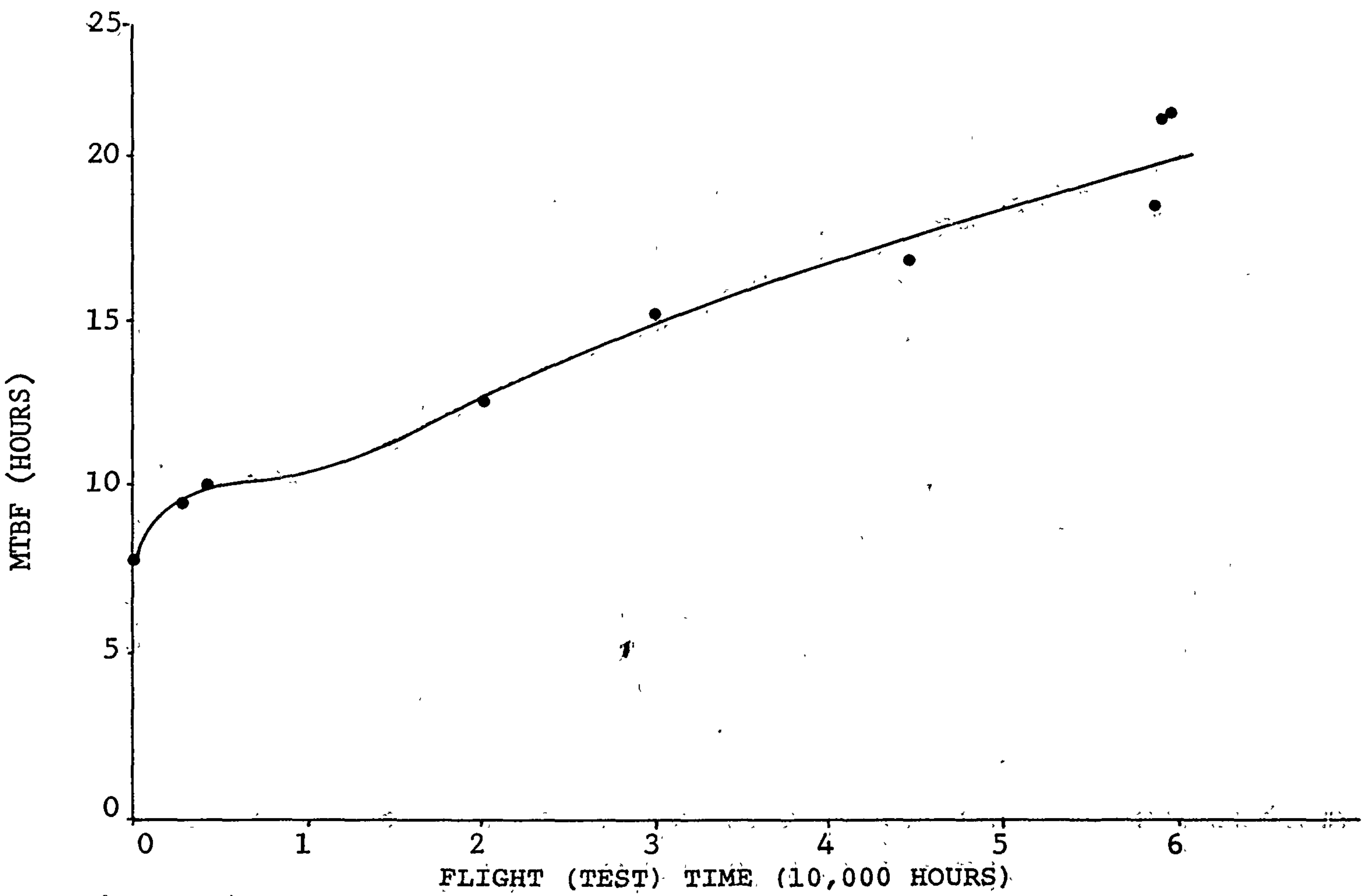

Figure 9. Reliability growth (MTBF) for UH-1D versus flight time (M&R Program monitored time, YUH-1D time and BHC test time).

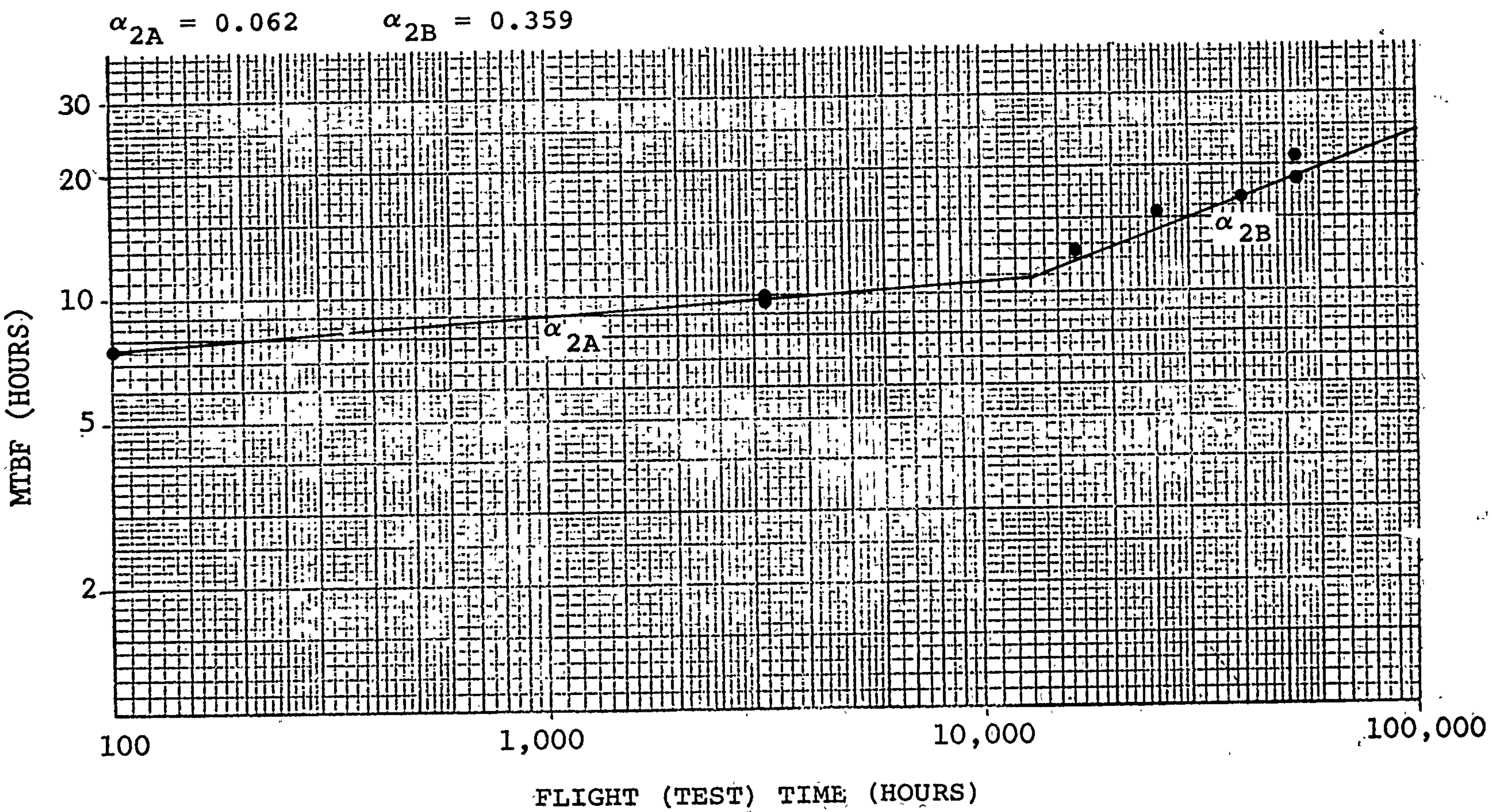

Figure 10. Reliability growth (MTBF) for UH-1D versus flight time (M&R Program monitored time).

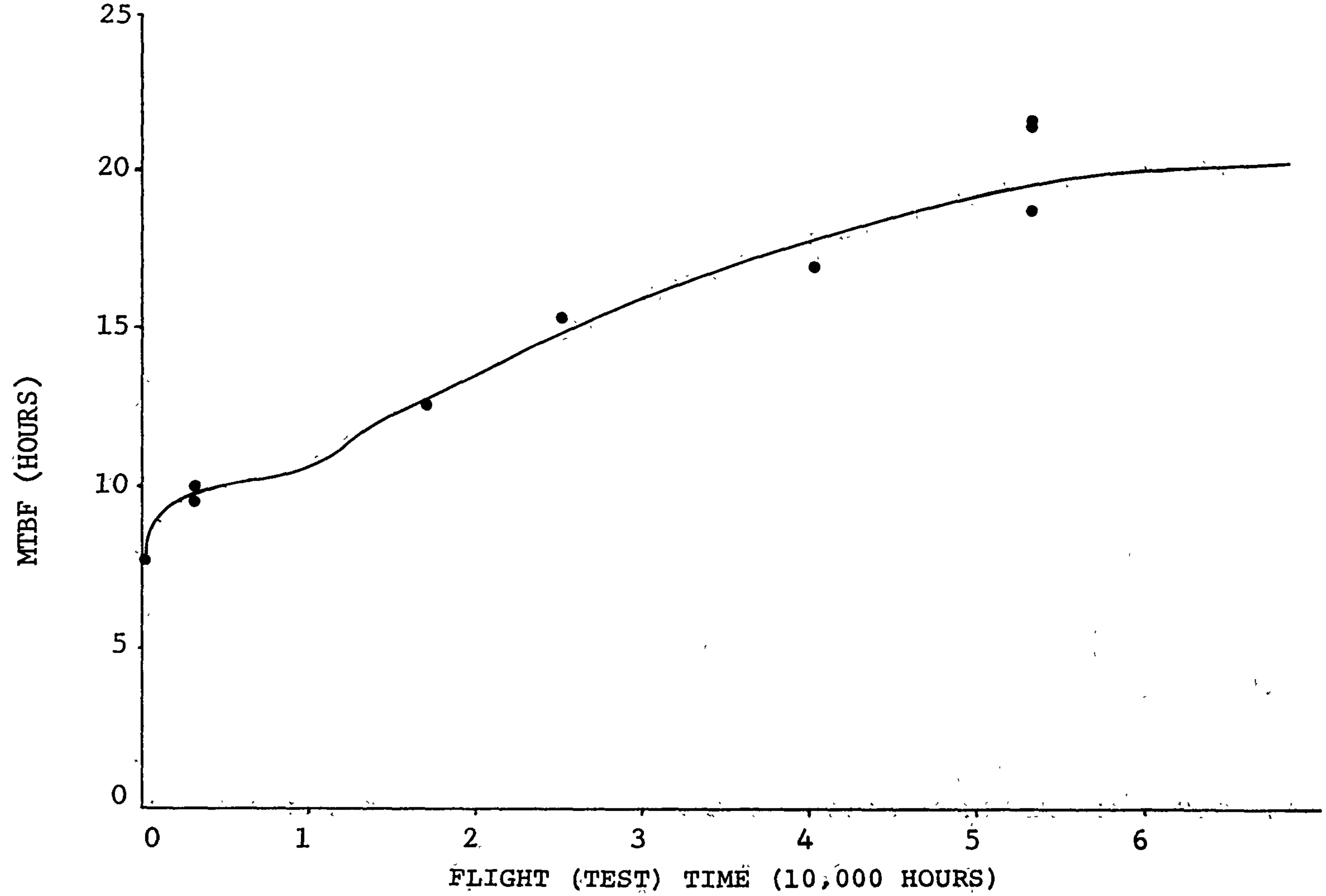

Figure 11. Reliability growth (MTBF) for UH-1D versus flight time (M&R Program monitored time).

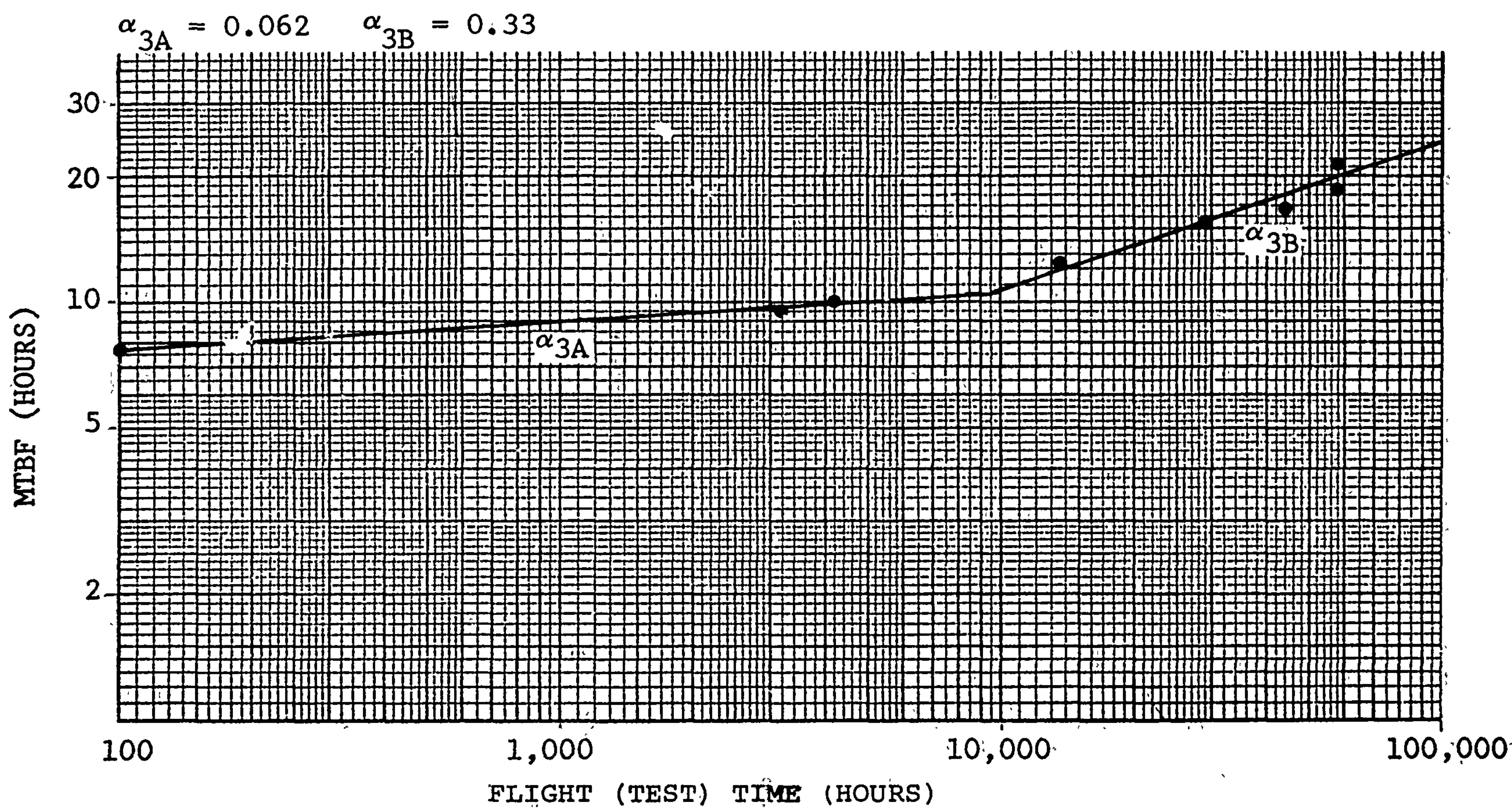

Figure 12. Reliability growth (MTBF) for UH-1D versus flight time (M&R Program monitored time and YUH-1D time).

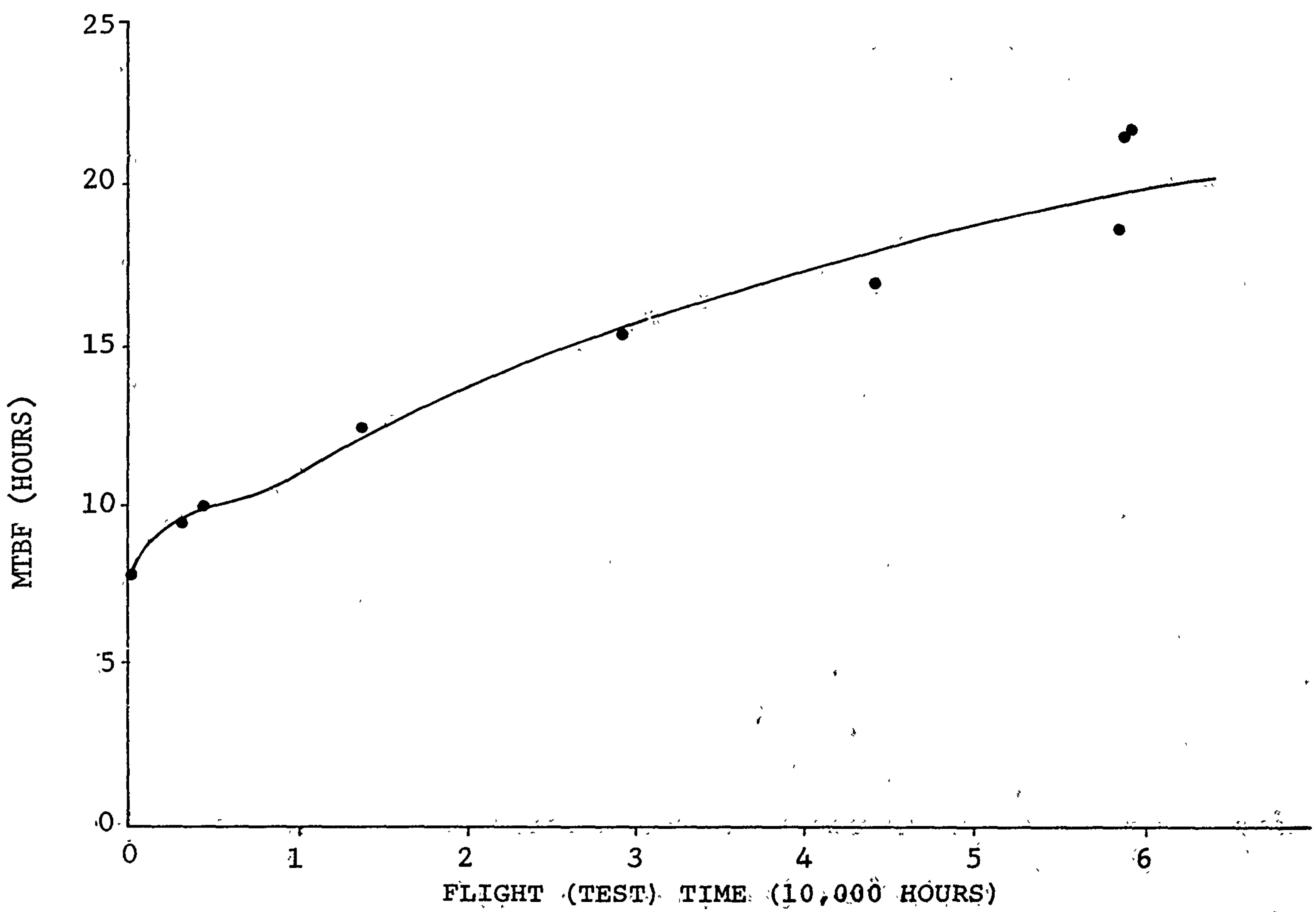

Figure 13. Reliability growth (MTBF) for UH-1D versus flight time (M&R Program monitored time and YUH-1D time).

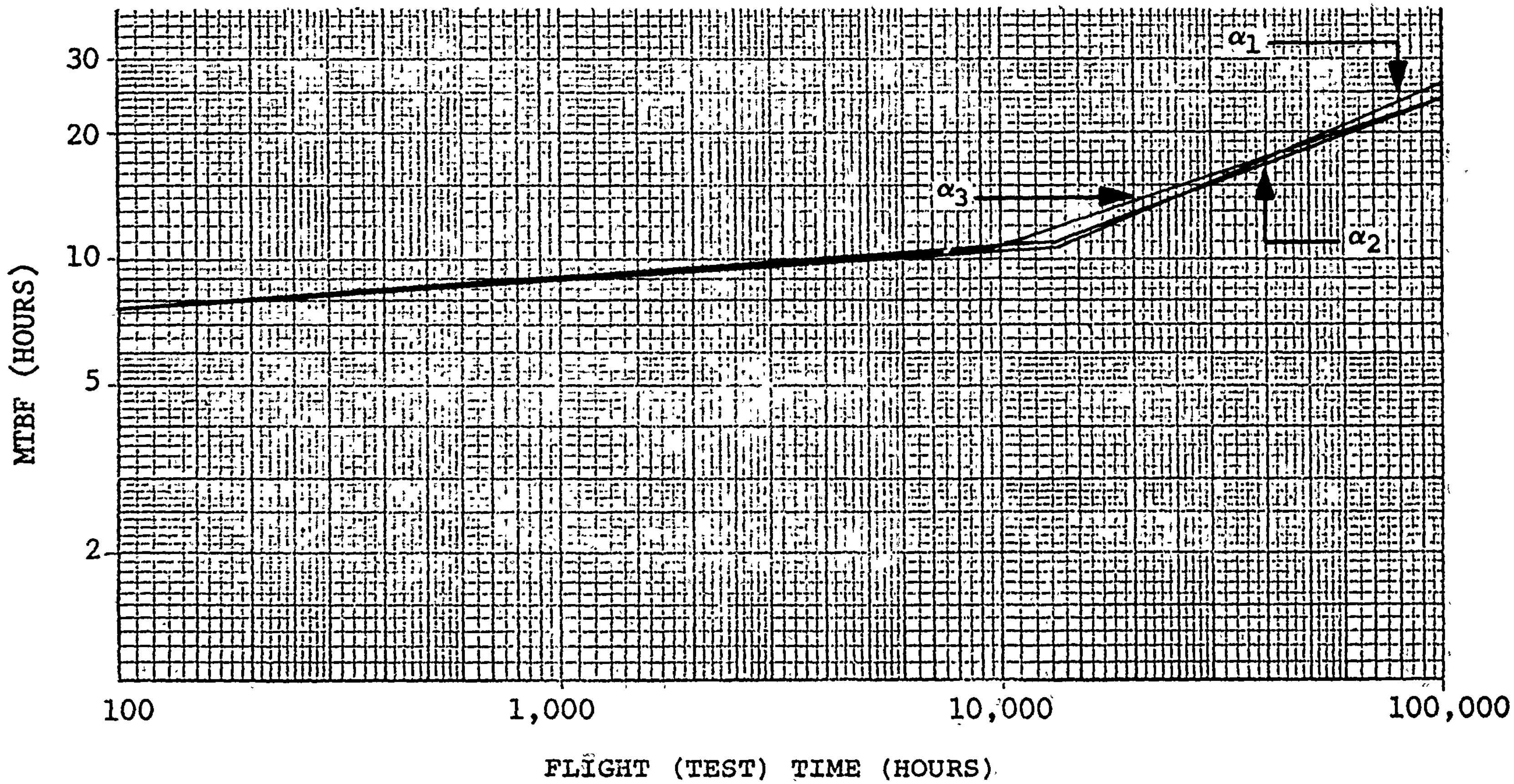

Figure 14. Comparison of UH-1D reliability growth curves with three different test hour combinations.

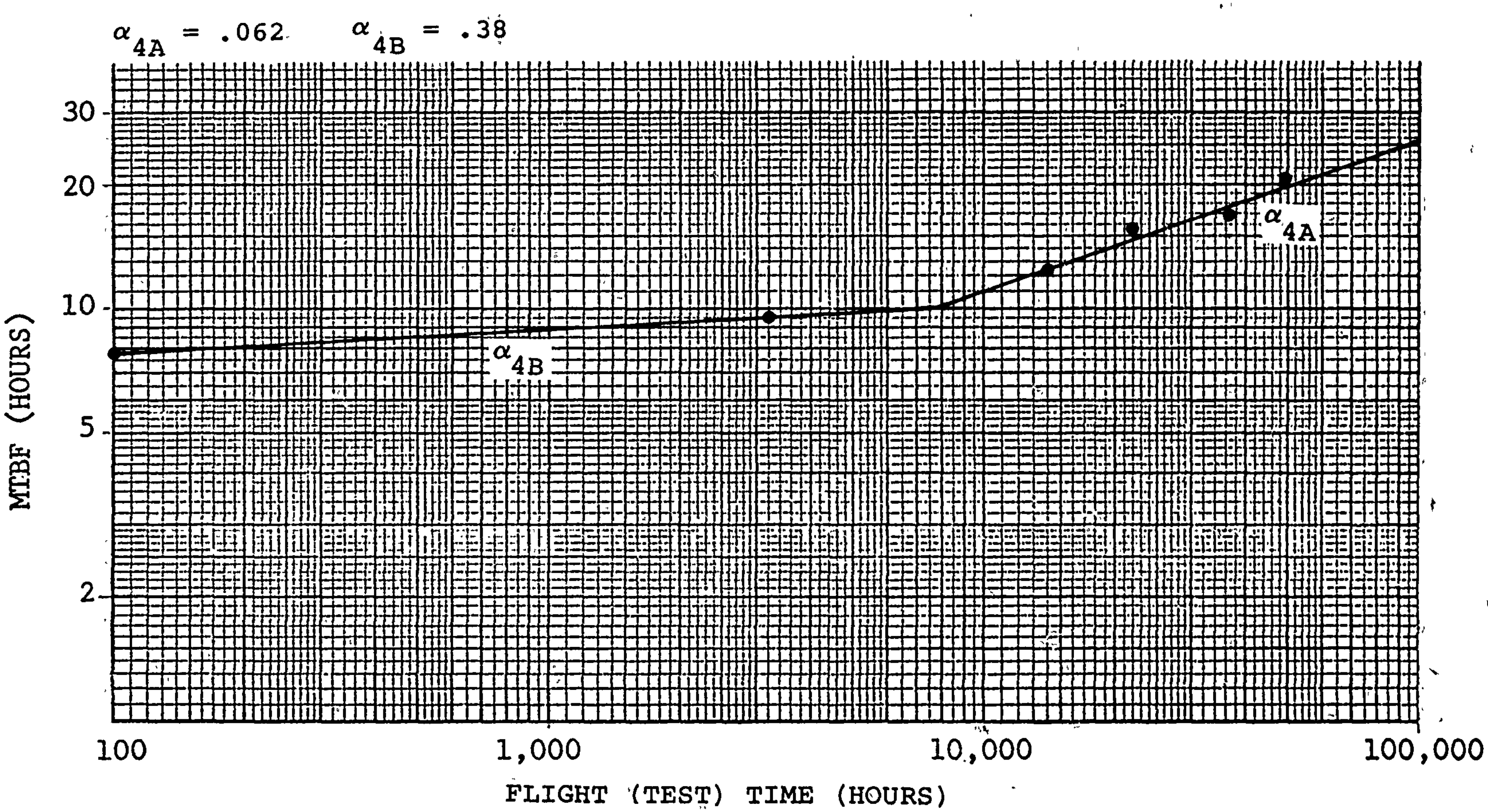

Figure 15. Reliability growth (MTBF) for UH-1D versus flight time. (M&R monitored time versus MTBF. Both incorporated and rejected improvements are included in the MTBF.)

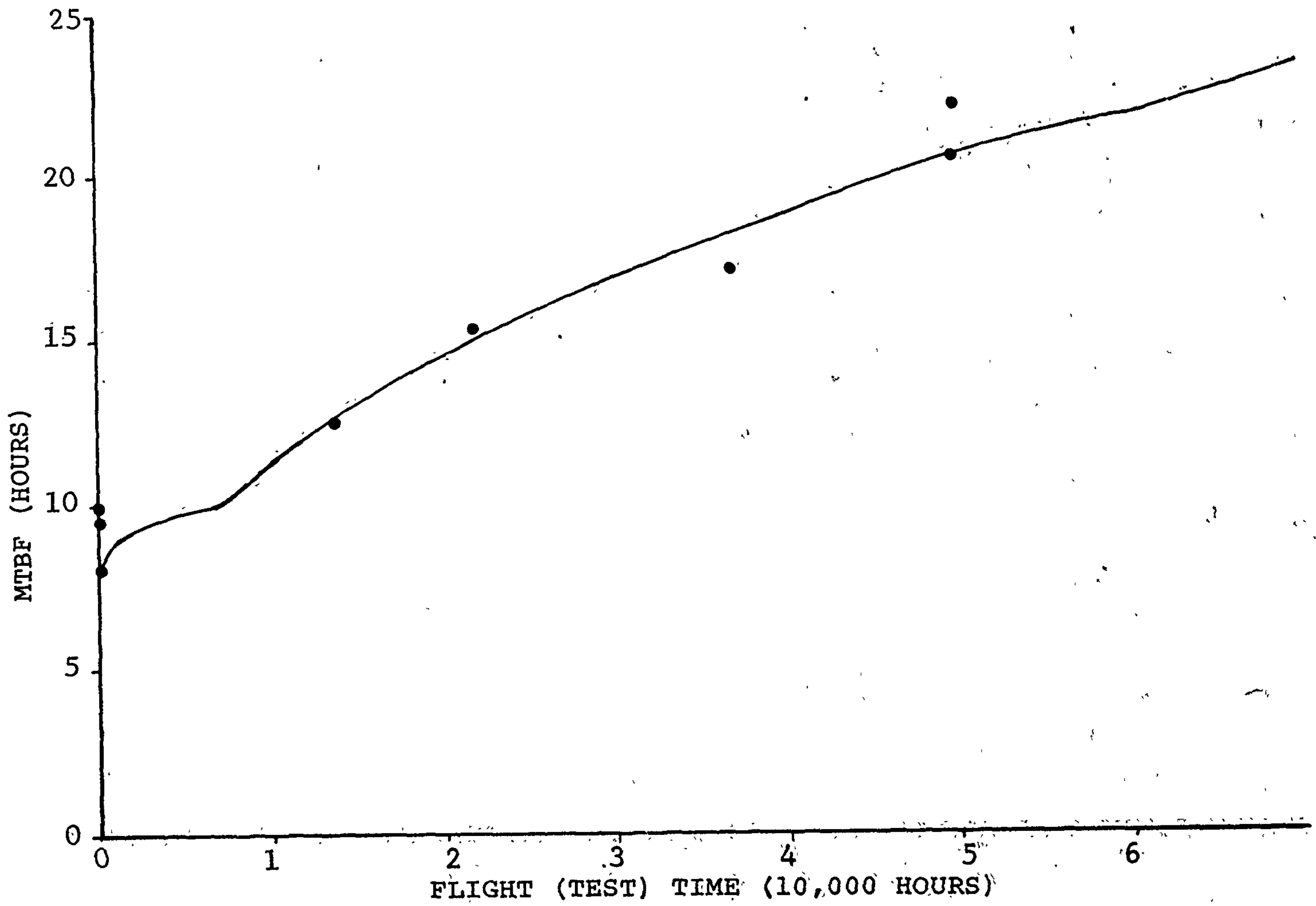

Figure 16. Reliability growth (MTBF) for UH-1D versus flight time. (M&R monitored time versus MTBF. Both incorporated and rejected improvements are included in the MTBF.)

TABLE 10. UH-1D DESIGN MTBF AND TEST TIME VERSUS CALENDAR QUARTER

CY by Qtr.		Design MTBF	M&R Time	+	Baseline Constant	=	Operating Hours Plot
63	1						
	2						
	3	10.1	0		3179		3179
	4	10.1	0		3179		3179
64	1	11.3	0		3179		3179
	2	11.7	2267		3179		5446
	3	11.7	9011		3179		12190
	4	13.7	13606		3179		16785
65	1	14.7	17682		3179		20861
	2	14.9	21205		3179		24384
	3	15.6	21946		3179		25125
	4	15.6	21946		3179		25125
66	1	16.3	21946		3179		25125
	2	18.3	29392		3179		32571
	3	18.6	36785		3179		39964
	4	18.6	44846		3179		48025
67	1	18.7	49947		3179		53126
	2	18.8	49947		3179		53126
	3	19.7	49947		3179		53126
	4	20.3	49947		3179		53126
68	1	21.0	49947		3179		53126
	2	21.1	49947		3179		53126
	3	21.4	49947		3179		53126
	4	21.4	49947		3179		53126

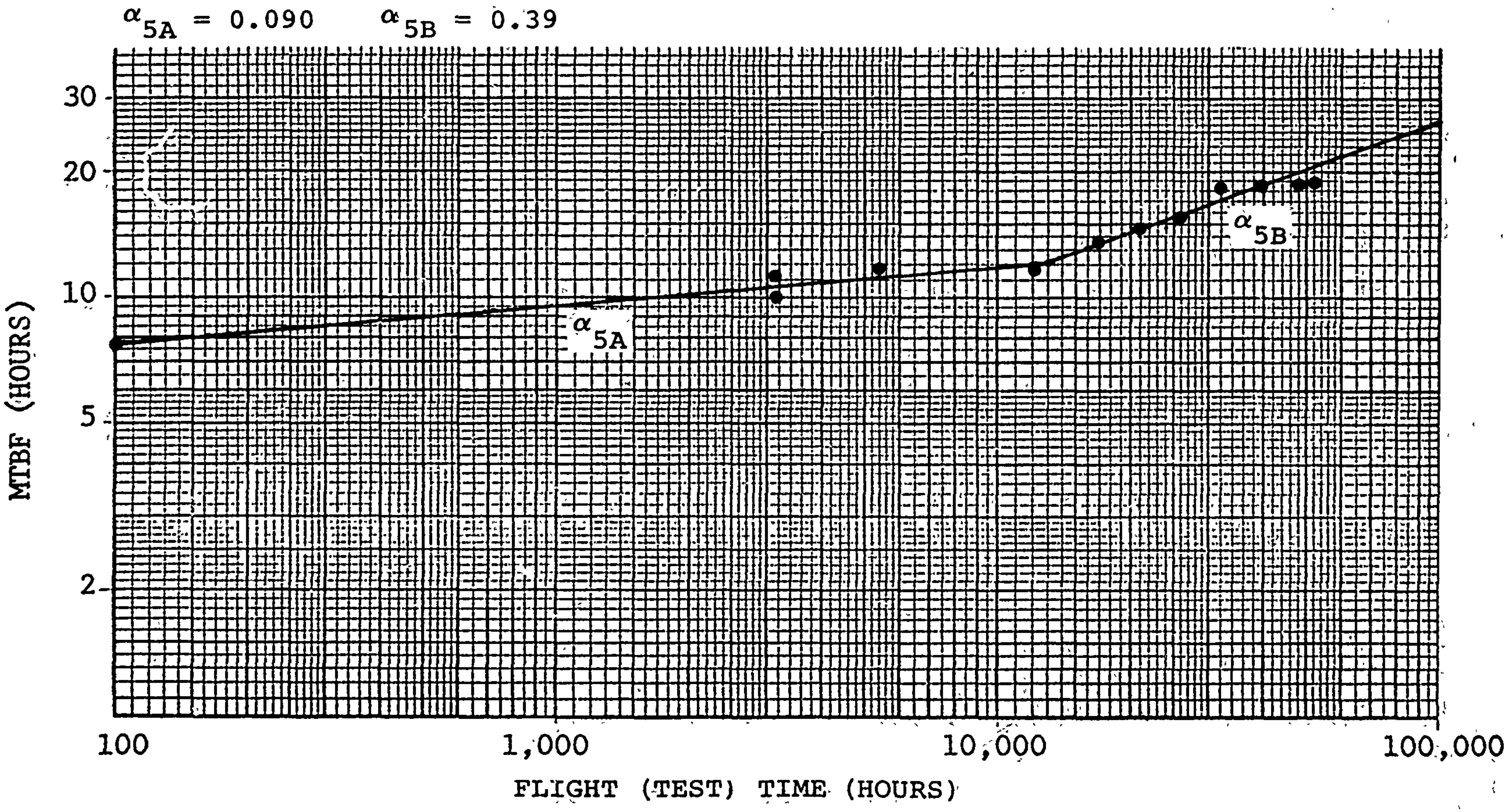

Figure 17. Reliability growth of the UH-1D design.

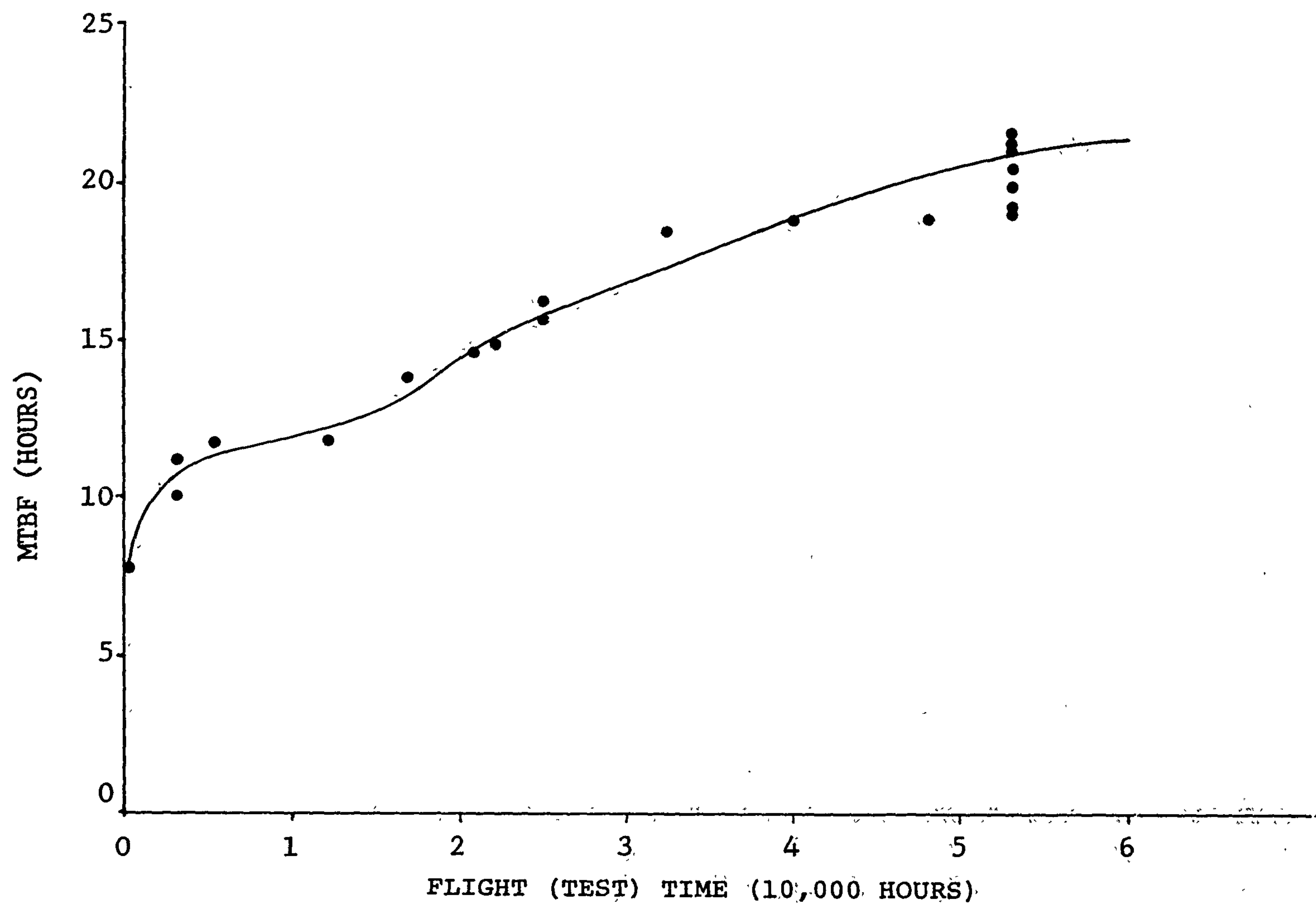

Figure 18. Reliability growth of the UH-1D design.

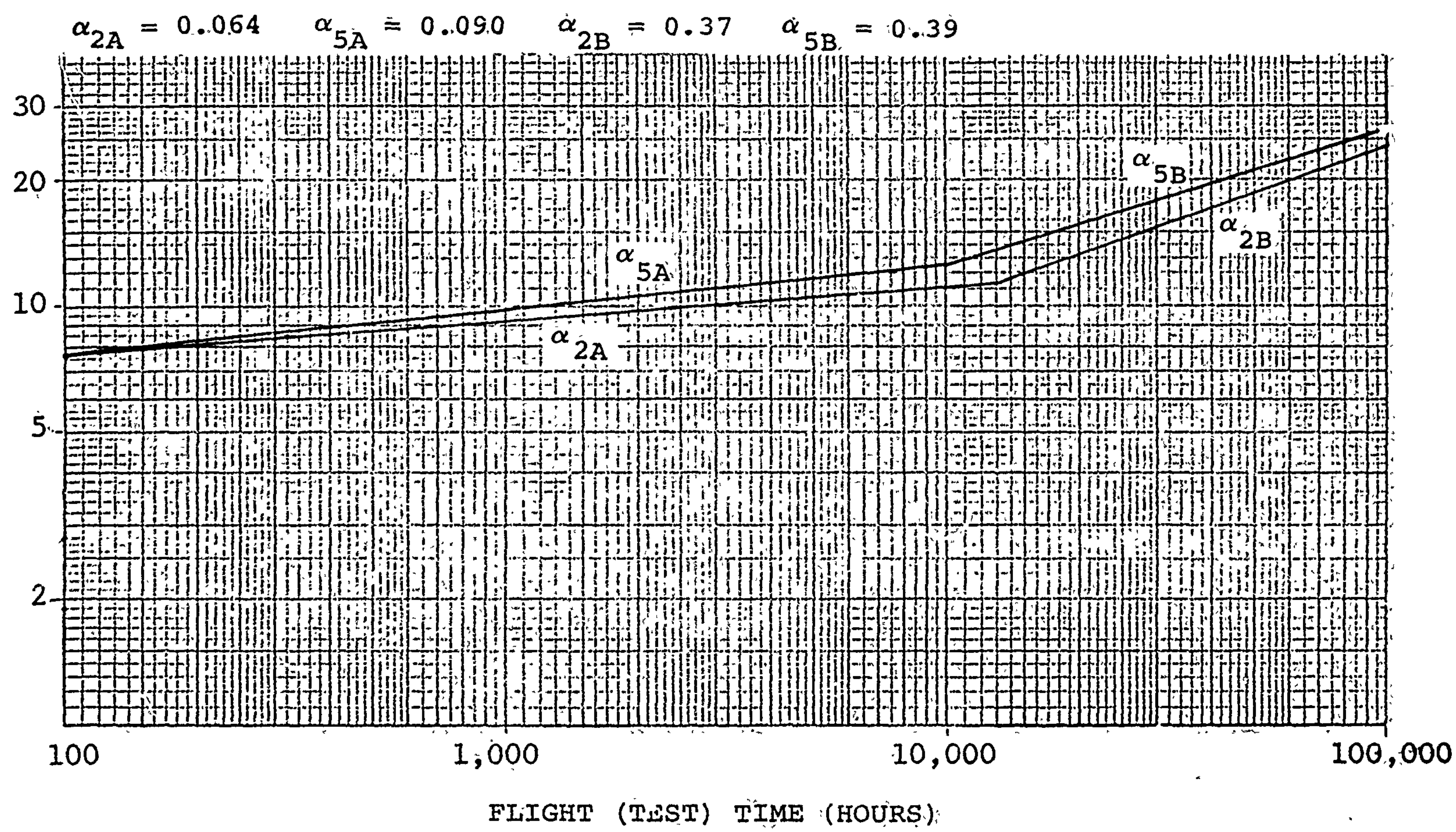

Figure 19. Reliability growth (MTBF) for UH-1D comparing reliability of design (α_5) with reliability of hardware (α_2).

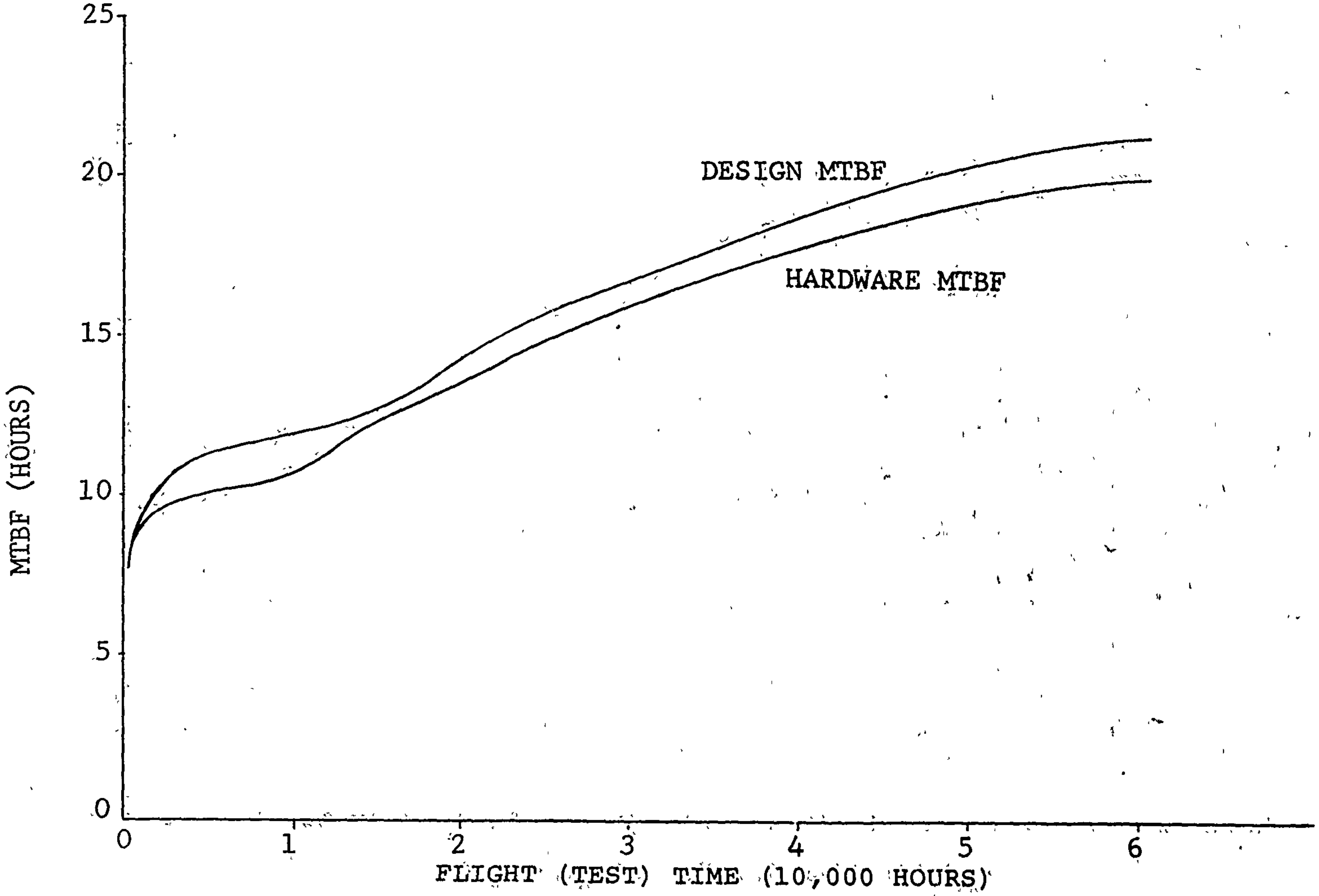

Figure 20. Reliability growth (MTBF) for UH-1D versus flight time (reliability of design versus reliability of hardware).

TABLE 11. UH-1D SUBSYSTEM FAILURE RATE DECREASE SUMMARY

SUBSYSTEM \ FISCAL YEAR	FAILURE RATE BY FISCAL YEAR PRODUCTION, λ: 62	63	64	65	66	67	68	69	* Δλ	** %	*** %
Airframe	.035526	.035526	.032034	.021714	.020097	.018996	.014333	.014262	.021264	59.9	36.0
Seats	.004406	.004406	.003594	.000663	.000663	.000663	.000663	.000663	.003743	85.0	6.3
Controls	.028947	.024902	.024902	.021577	.021327	.019084	.017473	.014654	.014293	49.4	24.2
Drive	.015574	.015574	.008056	.008056	.007671	.004441	.004401	.004401	.011173	71.7	18.9
Electrical	.001369	.001369	.001369	.001369	.001369	.001369	.001289	.001289	.000080	5.8	0.1
Fuel	.000966	.000966	.000966	.000966	.000966	.000966	.000966	.000966	0	0.0	0.0
Oil Cooling	.004481	.004481	.004481	.004481	.004481	.001713	.001713	.001713	.002768	61.8	4.7
Power Plant	.005367	.005367	.005367	.005367	.004077	.004077	.003957	.003957	.001410	26.3	2.4
Rotors	.006867	.006867	.006867	.006867	.006587	.005540	.004172	.004172	.002695	39.2	4.6
Caution/Warning	.002207	.002207	.001087	.001087	.001087	.001087	.001087	.000564	.001643	74.4	2.8
Aircraft Total	.105710	.101665	.088723	.072147	.068325	.057936	.050054	.046641	.059069	55.9	100.0

*Decrease in Subsystem Failure Rate
**Percentage Decrease in Subsystem Failure Rate
***Percentage Contribution to Total Decrease in Failure Rate

TABLE 12. UH-1D SUBSYSTEM FAILURE RATE PERCENTAGE CHANGE BY FISCAL YEAR

FISCAL YEAR / SUBSYSTEM	63		64		65		66		67		68		69		Total	
	*	**	*	**	*	**	*	**	*	**	*	**	*	**	*	**
Airframe	0.0	0.0	9.8	27.0	32.2	62.3	7.4	42.3	5.5	10.6	24.5	59.2	0.5	2.1	59.9	36.0
Seats	0.0	0.0	18.4	6.3	81.6	17.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.0	6.3
Controls	14.0	100.0	0.0	0.0	13.4	20.0	1.2	6.5	10.5	21.6	8.4	20.4	16.1	82.6	49.4	24.2
Drive	0.0	0.0	48.3	58.0	0.0	0.0	4.8	10.1	42.1	31.1	0.9	0.5	0.0	0.0	71.7	18.9
Electrical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	1.0	0.0	0.0	5.8	0.1
Fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil Cooling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.8	26.6	0.0	0.0	0.0	0.0	61.8	4.7
Power Plant	0.0	0.0	0.0	0.0	0.0	0.0	24.0	33.8	0.0	0.0	2.9	1.5	0.0	0.0	26.3	2.4
Rotors	0.0	0.0	0.0	0.0	0.0	0.0	4.1	7.3	15.9	10.1	24.7	17.4	0.0	0.0	39.2	4.6
Caution/Warning	0.0	0.0	50.7	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.1	15.3	74.4	2.8
Aircraft Total	11.0	100.0	12.7	100.0	18.7	100.0	5.3	100.0	15.2	100.0	13.6	100.0	6.8	100.0	55.9	100.0

*Percentage Decrease in Subsystem Failure Rate (from previous year)
**Percentage Contribution to Total Decrease in Failure Rate

TABLE 13. FLIGHT (TEST) TIME VERSUS MTBF FOR AH-1G

Fiscal Year	Accumulated Flight Time BHC/Army M&R Program	MTBF	MTBF**
FY 66 Lot 4 & 5 Off-Board	100	6.6*	6.6*
FY 66 Lot 6	1,002	6.7	6.7
FY 67	6,594	7.0	7.0
FY 68	24,884	8.1	8.2
FY 69	66,272	9.4	9.6
FY 70	66,272	9.6	9.9

* 100 hours shakedown is the earliest point at which off-board can be considered.

** Resultant MTBF's if failure rates for unincorporated corrections had been subtracted completely.

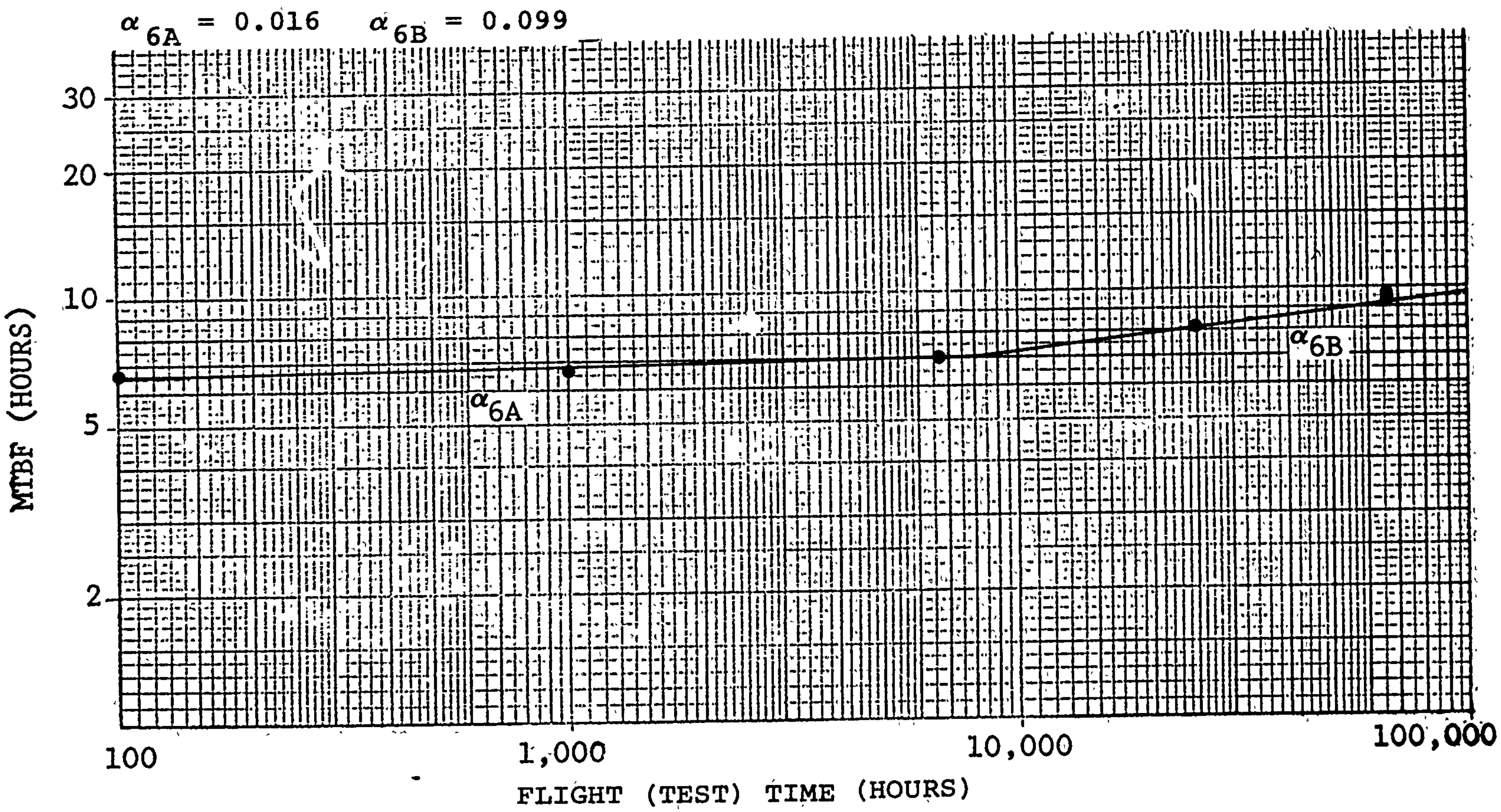

Figure 21. Reliability growth (MTBF) for AH-1G (M&R flight time versus observed MTBF).

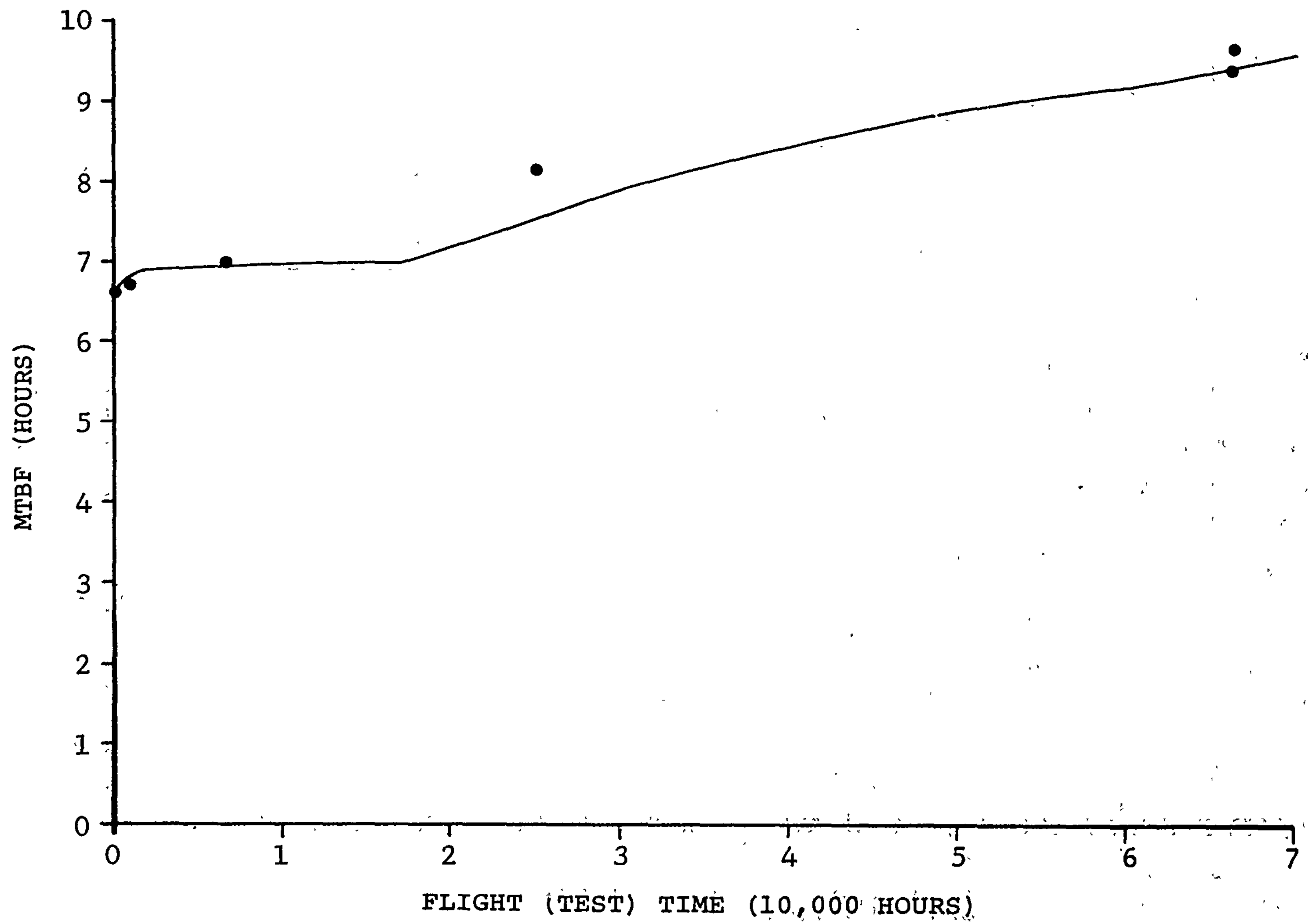

Figure 22. Reliability growth (MTBF) for AH-1G (M&R flight time versus observed MTBF).

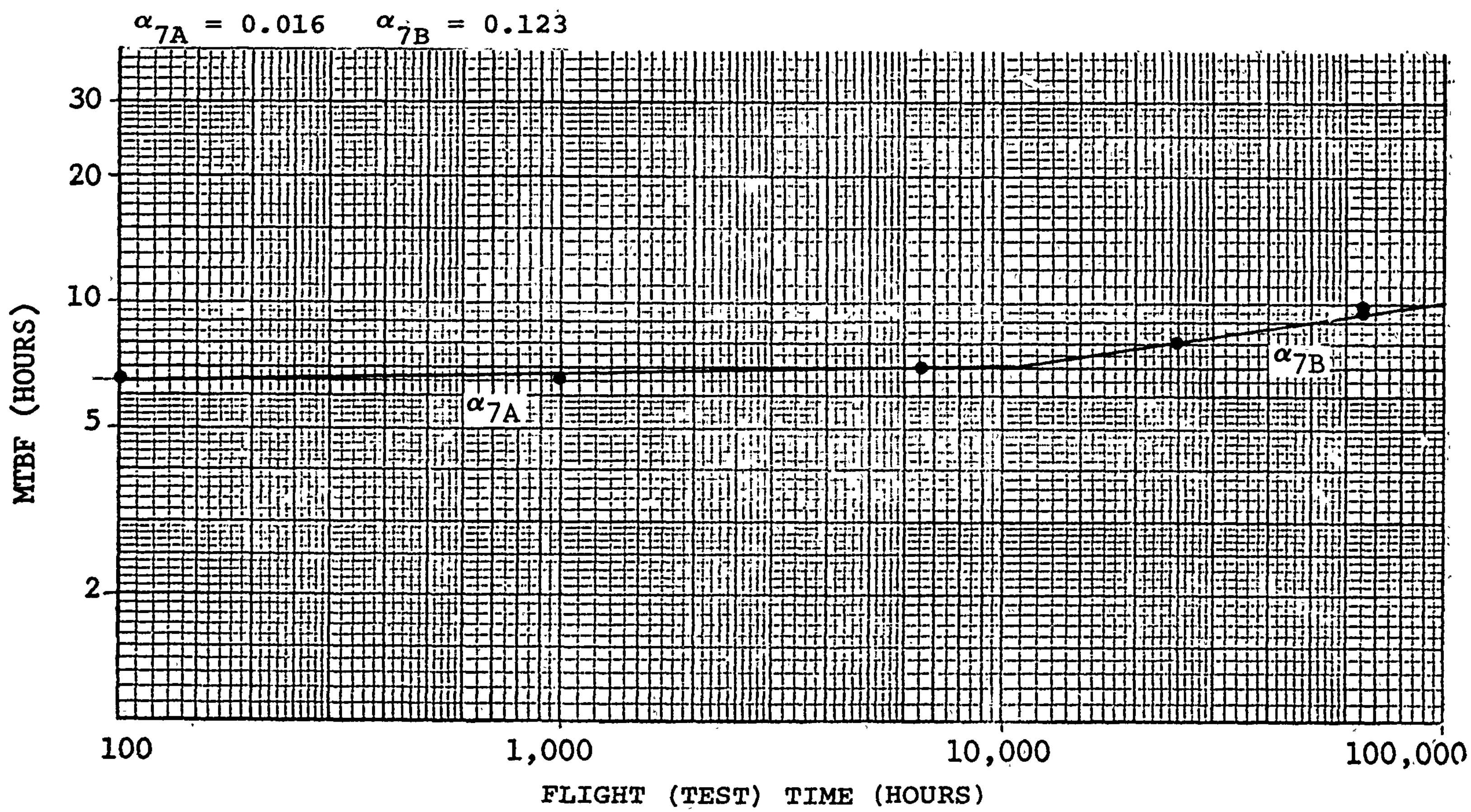

Figure 23. Reliability growth (MTBF) for AH-1G (M&R flight time versus MTBF.) (Both incorporated and rejected improvements are included in the MTBF.)

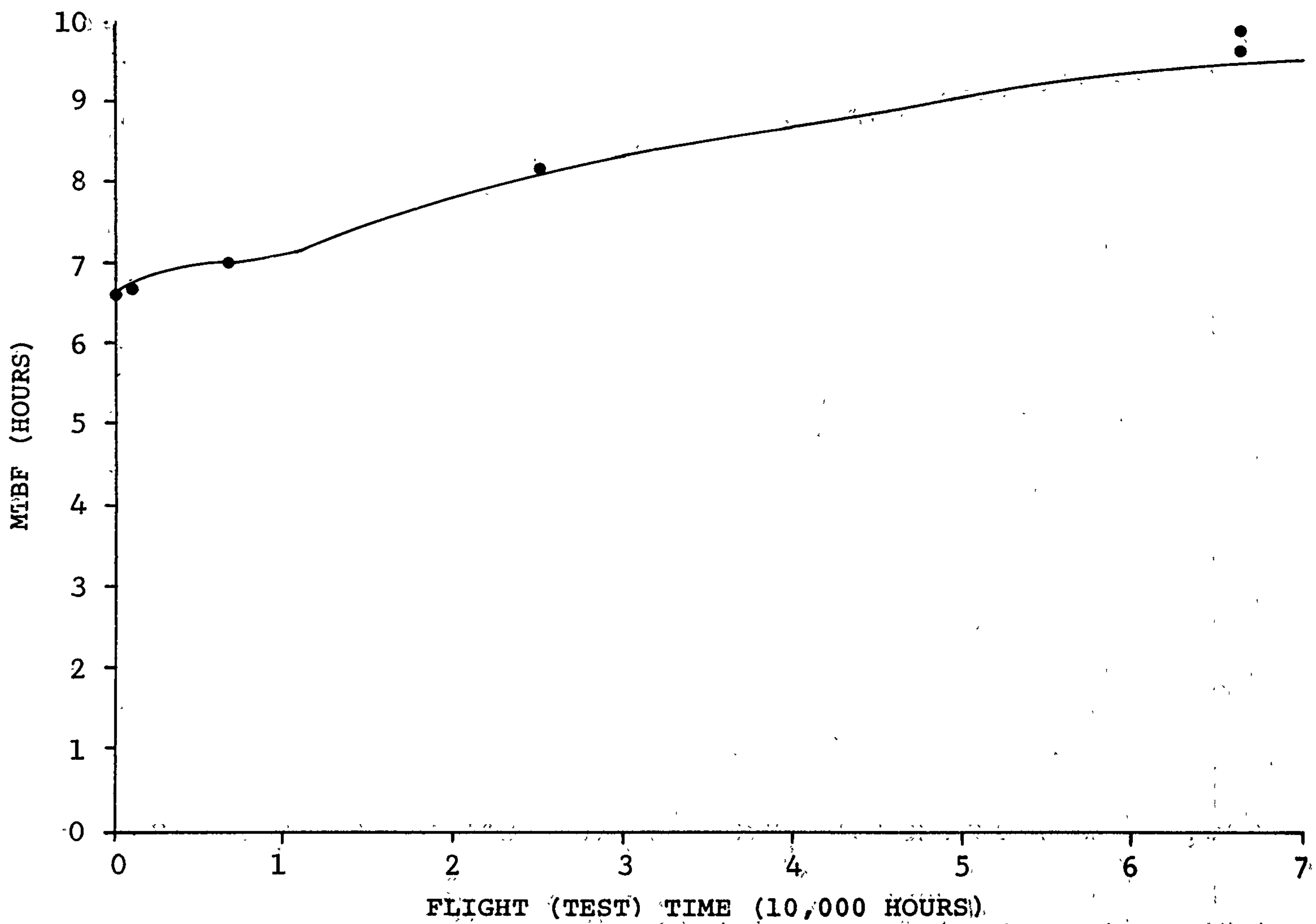

Figure 24. Reliability growth (MTBF) for AH-1G (M&R flight time versus MTBF.) (Both incorporated and rejected improvements are included in the MTBF.)

TABLE 14. AH-1G DESIGN MTBF AND TEST TIME VERSUS CALENDAR QUARTER

Calendar Quarters	Design MTBF	M&R Time (Operating Hr)
1967 - 2	6.6	38
- 3	6.6	1,002
- 4	6.8	4,710
1968 - 1	7.2	10,643
- 2	7.6	17,592
- 3	8.1	24,884
- 4	8.3	33,488
1969 - 1	8.3	43,020
- 2	9.1	52,930
- 3	9.3	62,675
- 4	9.3	66,272
1970 - 1	9.6	66,272
- 2	9.7	66,272

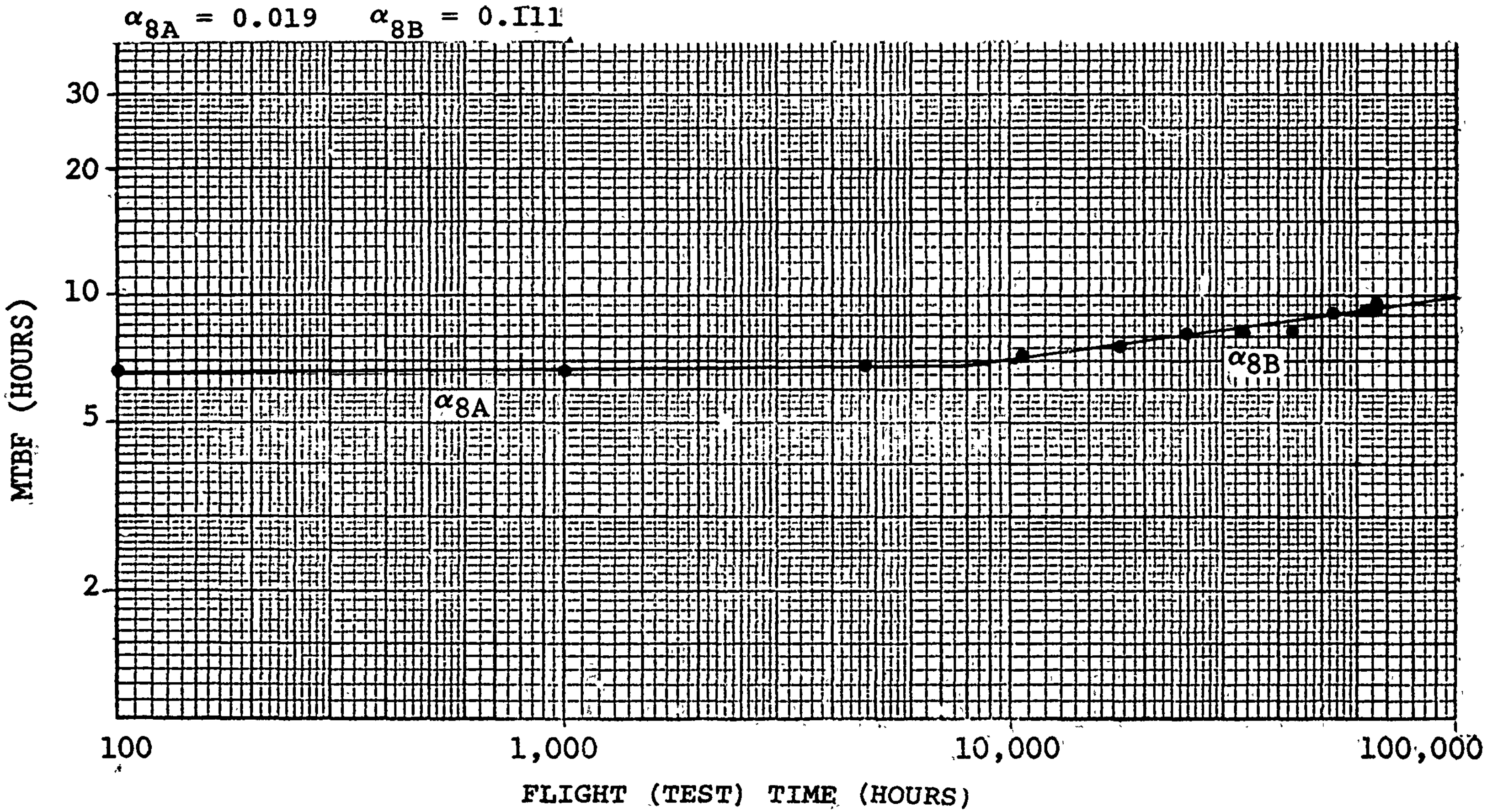

Figure 25. Reliability growth for AH-1G design.

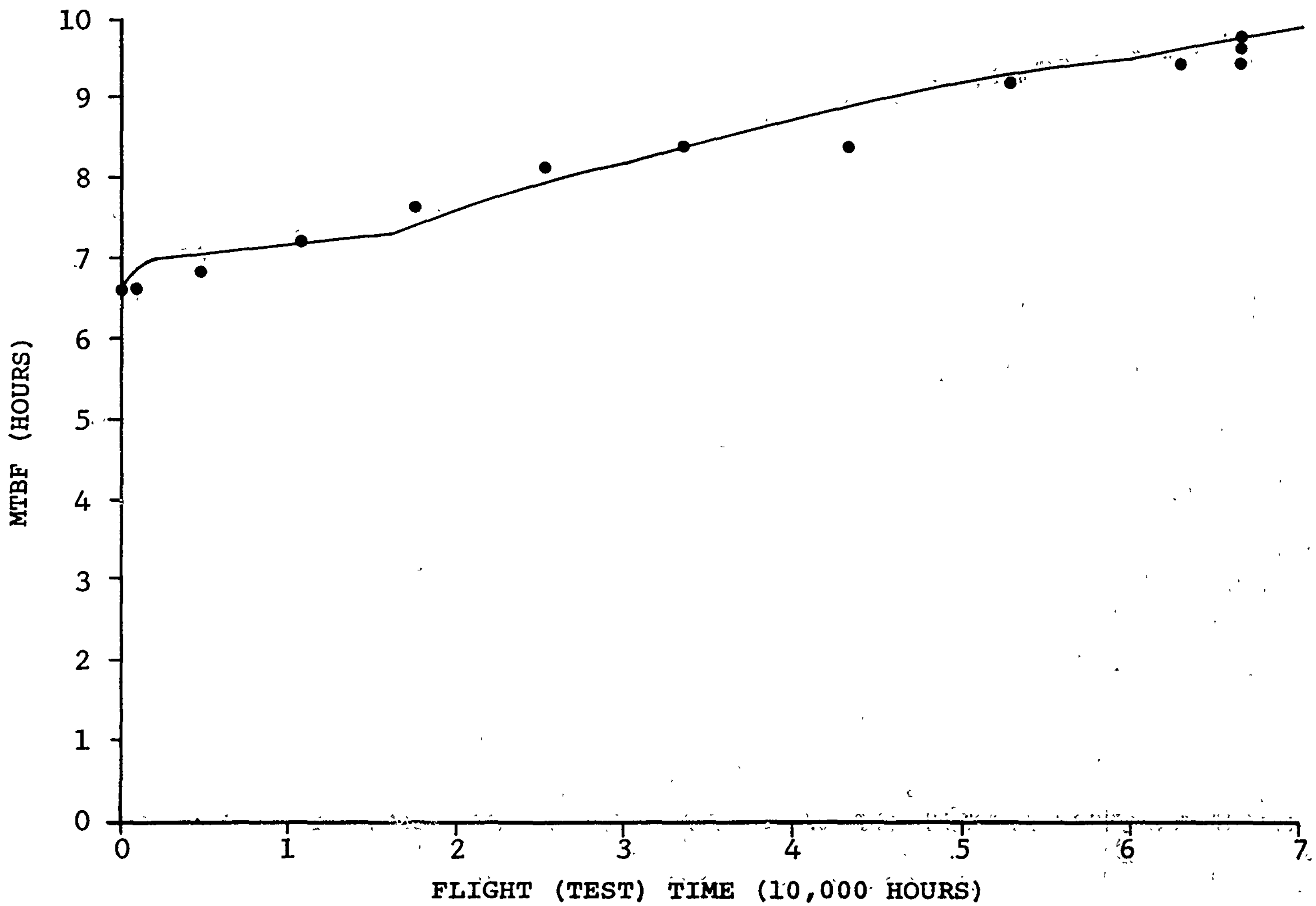

Figure 26. Reliability growth of AH-1G design.

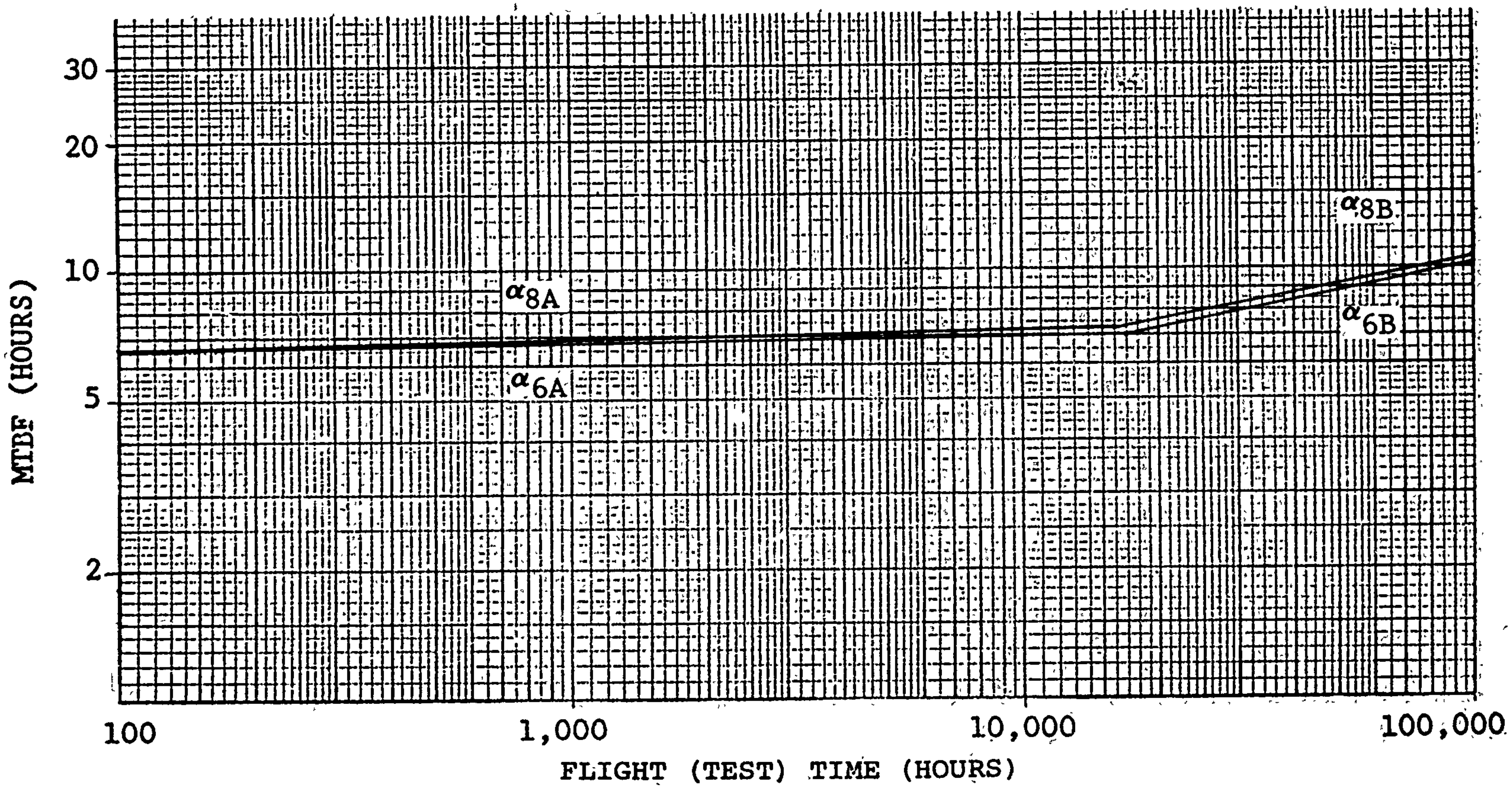

Figure 27. Reliability growth for AH-1G versus flight time (reliability of the design (α_8) versus the reliability of the hardware (α_6)).

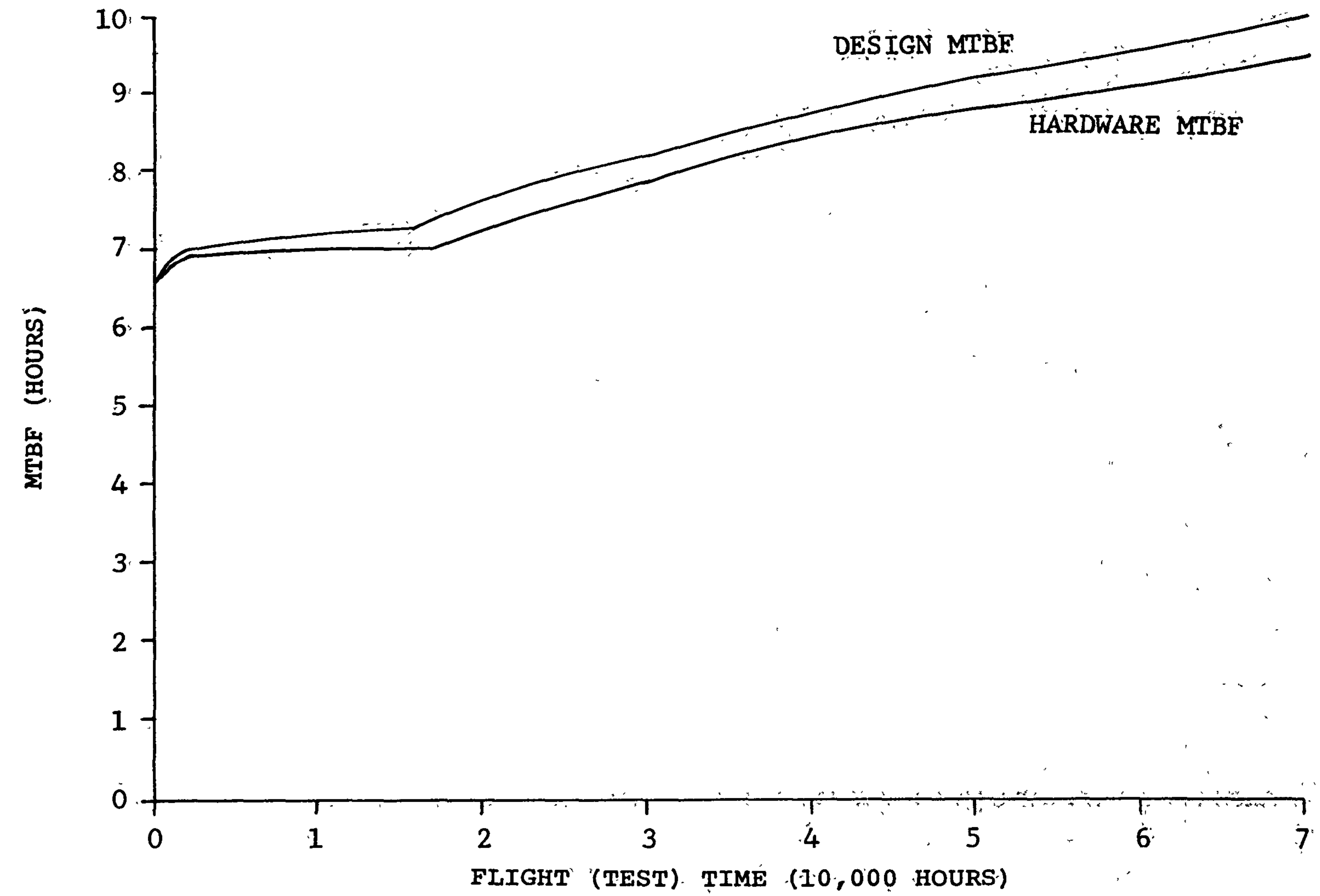

Figure 28. Reliability growth for the AH-1G versus flight time (reliability of the design (α_8) versus the reliability of the hardware (α_6)).

TABLE 15. AH-1G SUBSYSTEM FAILURE RATE DECREASE SUMMARY

SUB-SYSTEM / FISCAL YEAR	FAILURE RATES BY FISCAL YEAR PRODUCTION 66	67	68	69	70	Decrease in Subsystem Failure Rate	Percentage Decrease in Subsystem Failure Rate	Percentage Contribution to Total Decrease in Failure Rate
Airframe	.037184	.033969	.028537	.026146	.025271	.011913	32.0	24.7
Seats	.001071	.001071	.000860	.000860	.000860	.000211	19.7	0.5
Controls	.034250	.031157	.029336	.020322	.018551	.015699	45.8	32.5
Drive	.009529	.009529	.009073	.006095	.006095	.003434	36.0	7.1
Electrical	.029366	.028330	.021891	.021891	.021891	.007475	25.5	15.5
Fuel	.001494	.001494	.001494	.001494	.001494	0	0.0	0.0
Hydraulic	.004634	.004634	.004379	.004248	.004248	.000386	8.3	0.8
Instr. Instl	.001931	.001931	.001931	.001247	.001247	.000684	35.4	1.4
Oil Cooling	.004650	.004485	.000785	.000785	.000785	.003865	83.1	8.0
Power Plant	.009552	.009016	.008122	.007801	.007801	.001751	18.3	3.6
Rotors	.009026	.009026	.008983	.008772	.008772	.000254	2.8	0.5
Caution/Warn	.006517	.006517	.006247	.004879	.004879	.001638	25.1	3.4
Aux. Equip.	.002712	.002712	.001886	.001886	.001755	.000957	35.3	2.0
Aircraft Totals	.151916	.143871	.123524	.106426	.103649	.048267	31.8	100.0

TABLE 16. AH-1G SUBSYSTEM PERCENTAGE CONTRIBUTION TO TOTAL FAILURE RATE DECREASE

Subsystem	A % of Original Total Failure Rate (FY66)	B % Contribution to Total Decrease In Failure Rate	C Subsystem Improvement Factor B/A
Airframe	24.4	24.7	1.01
Seats	0.7	0.5	0.71
Controls	22.5	32.5	1.44
Drive	6.3	7.1	1.13
Electrical	19.3	15.5	0.80
Fuel	1.0	0.0	0.00
Hydraulic	3.1	0.8	0.26
Instr. Instl.	1.3	1.4	1.08
Oil Cooling	3.1	8.0	2.58
Power Plant	6.3	3.6	0.57
Rotors	5.9	0.5	0.08
Caution/Warning	4.3	3.4	0.79
Auxiliary Equipment	1.8	2.0	1.11

TABLE 17. AH-1G SUBSYSTEM FAILURE RATE PERCENTAGE CHANGE BY FISCAL YEAR

FISCAL YEAR / SUBSYSTEM	67		68		69		70		Total	
	*	**	*	**	*	**	*	**	*	**
Airframe	8.6	40.0	16.0	26.7	8.4	14.0	3.3	31.5	32.0	24.7
Seats	0.0	0.0	19.7	1.0	0.0	0.0	0.0	0.0	19.7	0.5
Controls	9.0	38.4	5.8	8.9	30.7	52.7	8.7	63.8	45.8	32.5
Drive	0.0	0.0	4.8	2.2	31.3	17.4	0.0	0.0	36.0	7.1
Electrical	3.5	12.9	22.7	31.6	0.0	0.0	0.0	0.0	25.5	15.5
Fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydraulics	0.0	0.0	5.5	1.3	3.0	0.8	0.0	0.0	8.3	0.8
Instr. Instl	0.0	0.0	0.0	0.0	35.4	4.0	0.0	0.0	35.4	1.4
Oil Cooling	3.5	2.0	82.5	18.3	0.0	0.0	0.0	0.0	83.1	8.0
Power Plant	5.6	6.7	9.9	4.4	4.0	1.9	0.0	0.0	18.3	3.6
Rotors	0.0	0.0	0.5	0.2	2.3	1.2	0.0	0.0	2.8	0.5
Caution/Warning	0.0	0.0	4.1	1.3	21.9	8.0	0.0	0.0	25.1	3.4
Aux. Equipment	0.0	0.0	30.5	4.1	0.0	0.0	6.9	4.7	35.3	2.0
Aircraft Totals	5.3	100.0	14.1	100.0	13.8	100.0	2.6	100.0	31.8	100.0

*Percentage Decrease in Subsystem Failure Rate
**Percentage Contribution to Total Decrease in Failure Rate

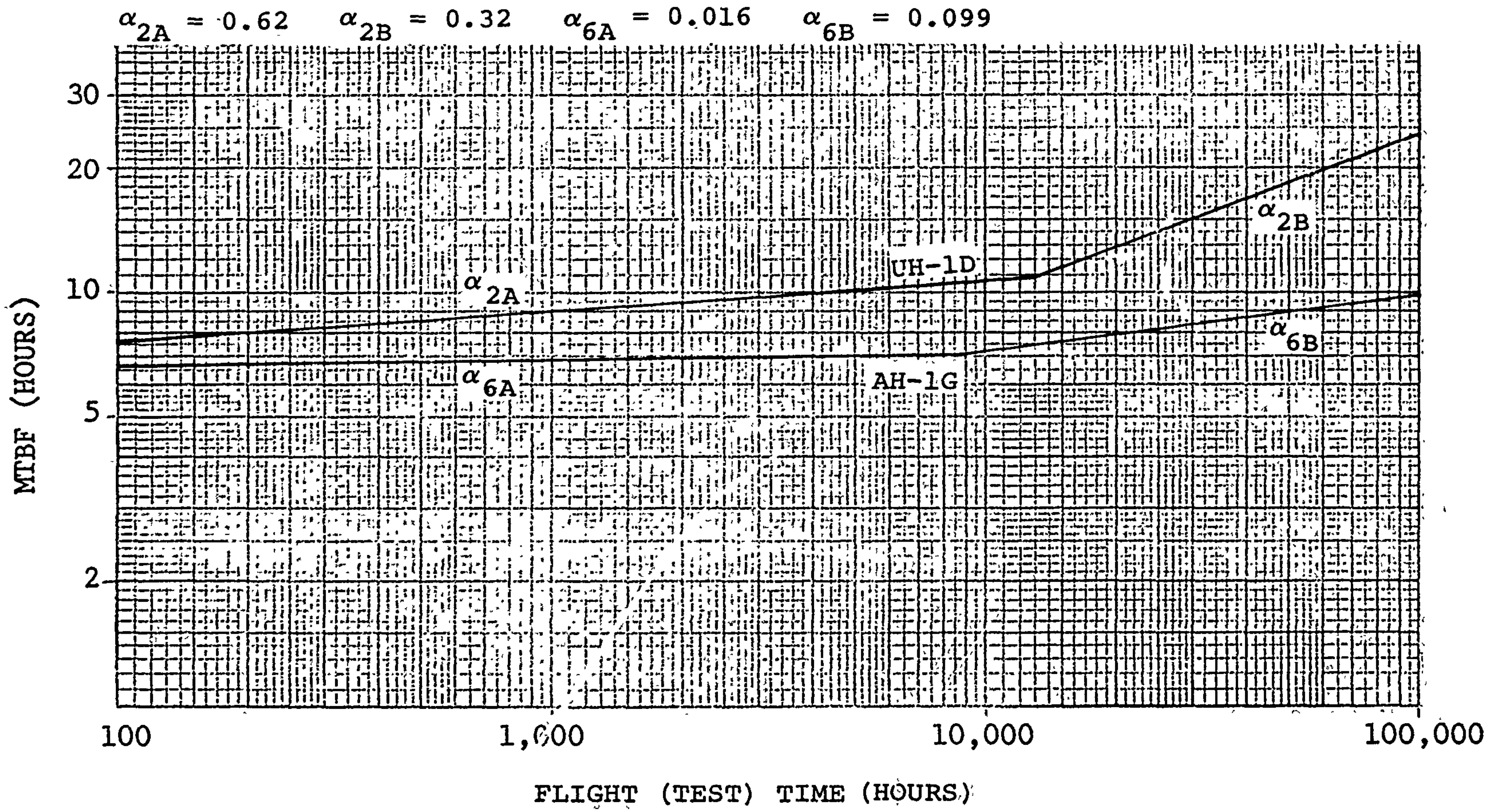

Figure 29. UH-1D and AH-1G growth curves compared.

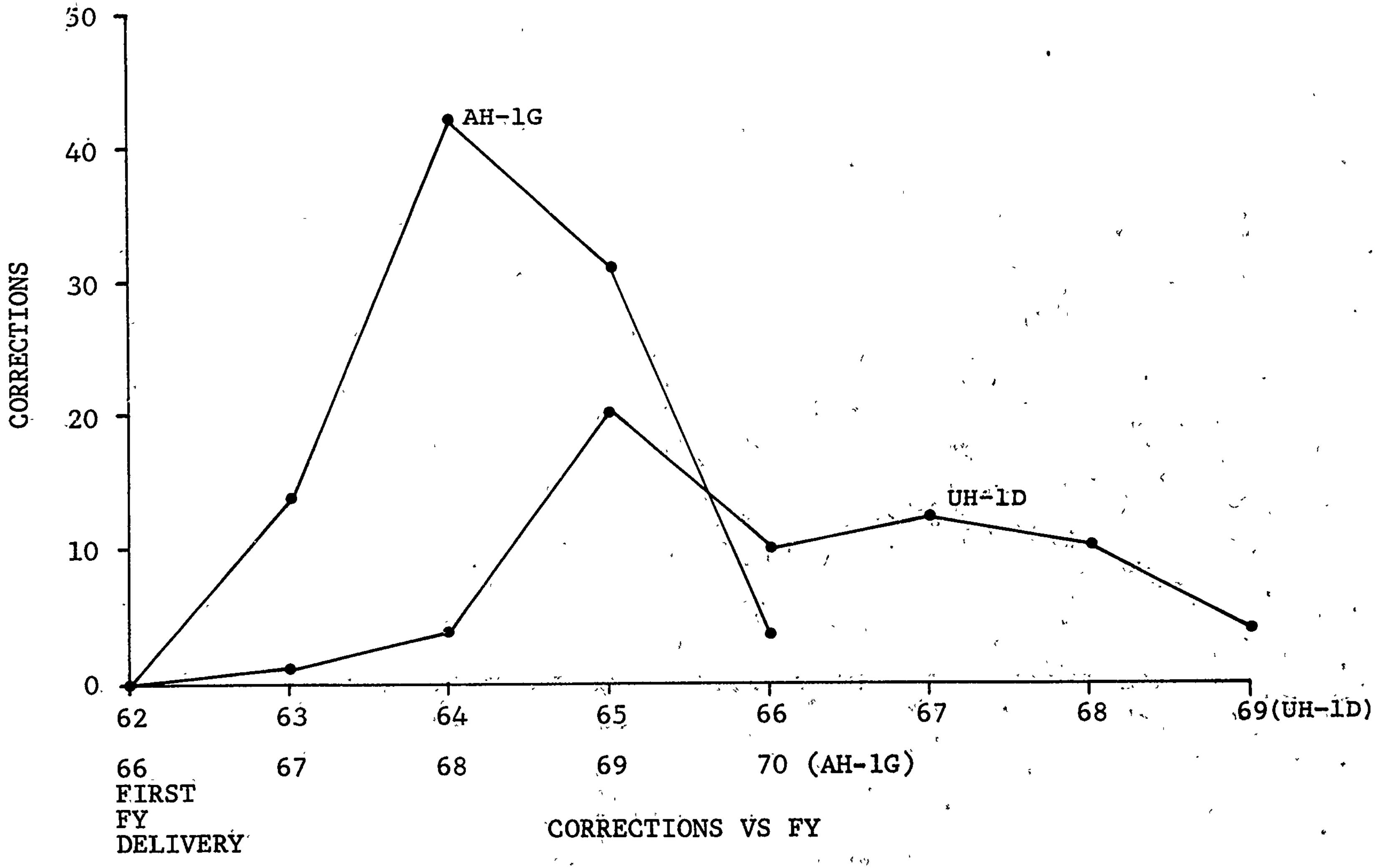

Figure 30. Number of problem corrections versus fiscal year configuration.

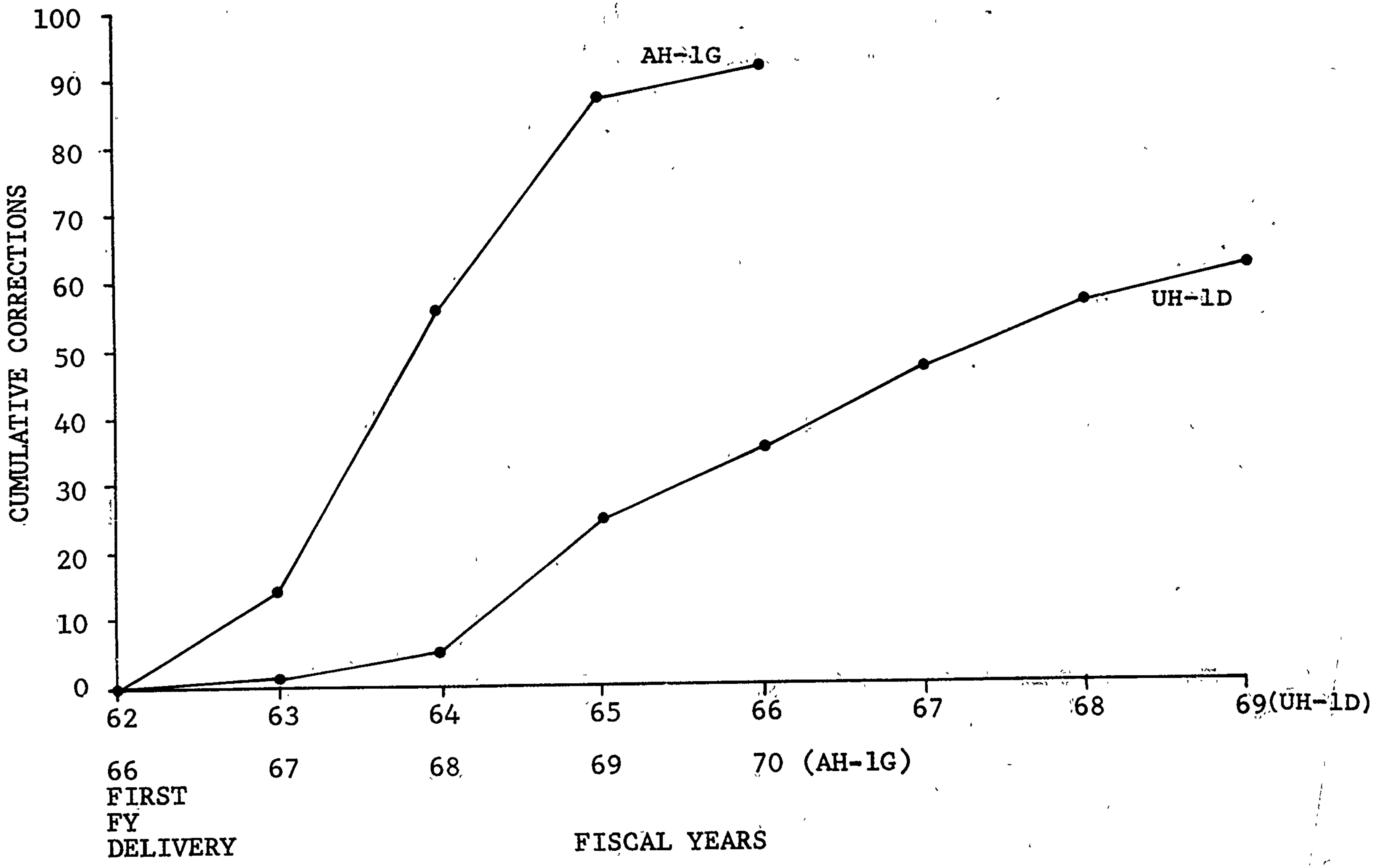

Figure 31. Cumulative corrective actions versus fiscal year configuration.

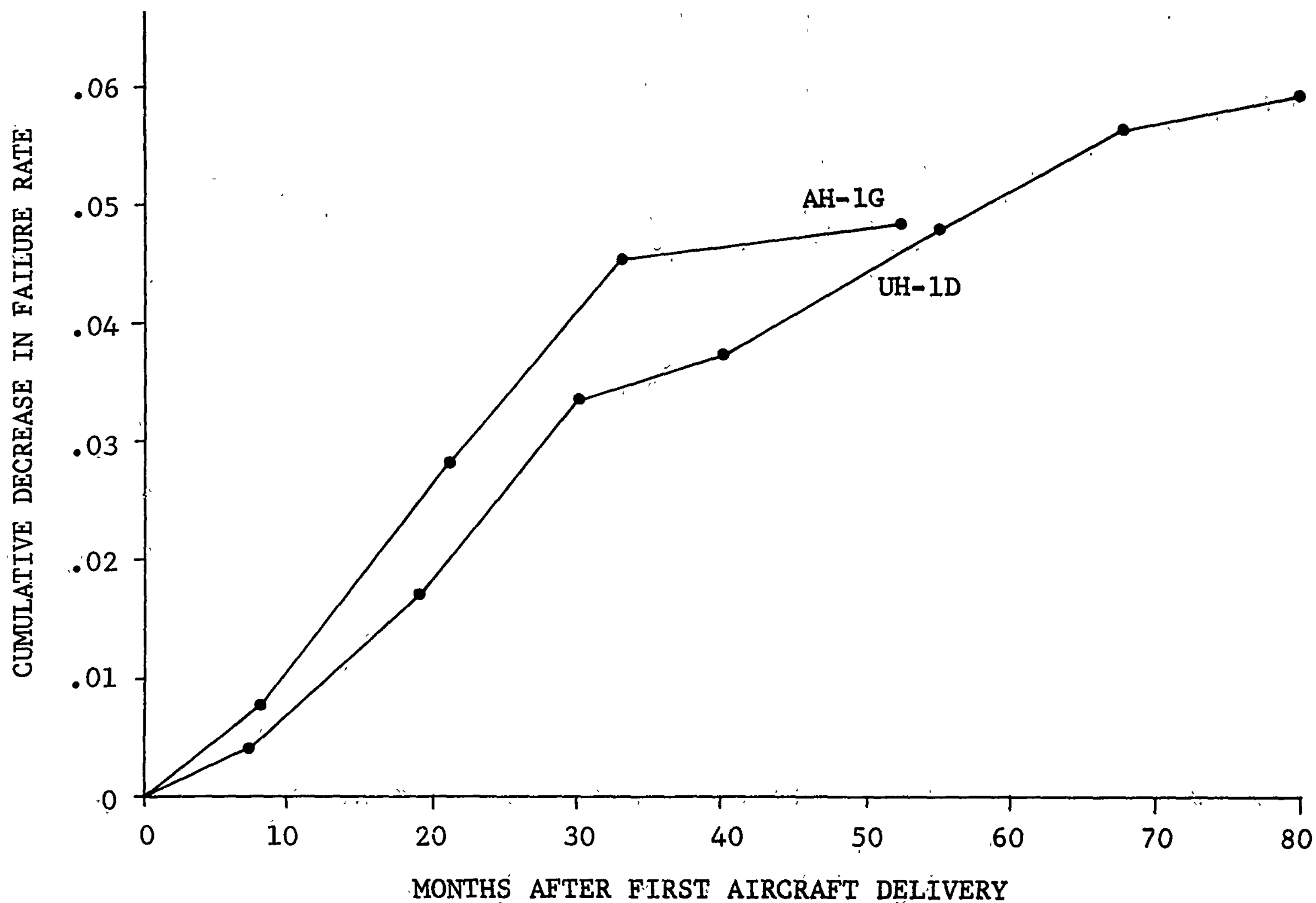

Figure 32. Cumulative decrease in failure rate versus months after first aircraft delivery.

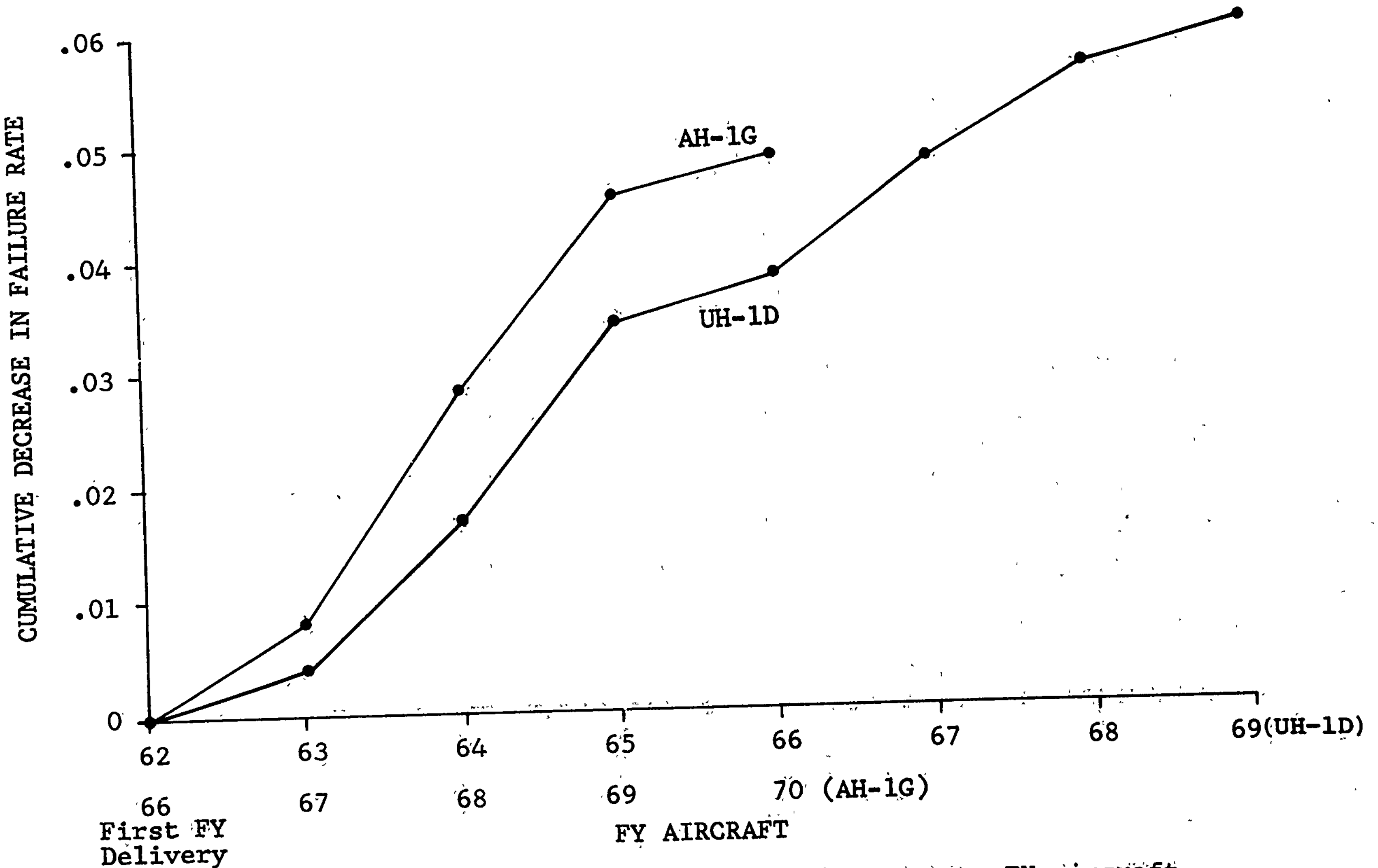

Figure 33. Cumulative decrease in failure rate versus FY aircraft.

TABLE 18. UH-1D SUBSYSTEM FAILURE RATE PERCENTAGE CHANGE - CUMULATIVE

FISCAL YEAR	63		64		65		66		67		68		69	
SUBSYSTEM	*	**	*	**	*	**	*	**	*	**	*	**	*	**
Airframe	0.0	0.0	9.8	20.6	38.9	41.2	43.4	41.3	46.5	34.6	59.7	38.1	59.9	36.0
Seats	0.0	0.0	18.4	4.8	85.0	11.1	85.0	10.0	85.0	7.8	85.0	6.7	85.0	6.3
Controls	14.0	100.0	14.0	23.8	25.6	22.0	26.3	20.4	30.1	20.7	39.6	20.6	49.4	24.2
Drive	0.0	0.0	48.3	44.3	48.3	22.4	50.7	21.1	71.5	23.3	71.7	20.1	71.7	18.9
Electrical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.2	5.8	0.1
Fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil Cooling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.8	5.8	61.8	5.0	61.8	4.7
Power Plant	0.0	0.0	0.0	0.0	0.0	0.0	24.0	3.5	24.0	2.7	26.3	2.5	26.3	2.4
Rotors	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.7	19.3	2.8	39.2	4.8	39.2	4.6
Caution/Warning	0.0	0.0	50.7	6.5	50.7	3.3	50.7	3.0	50.7	2.3	74.4	2.0	74.4	2.8
Aircraft Total	3.8	100.0	16.1	100.0	31.8	100.0	35.4	100.0	45.2	100.0	52.6	100.0	55.9	100.0

*Percentage Decrease in Subsystem Failure Rate
**Percentage Contribution to Total Decrease in Failure Rate

TABLE 19. AH-1G SUBSYSTEM FAILURE RATE PERCENTAGE CHANGE - CUMULATIVE

FISCAL YEAR / SUBSYSTEM	67		68		69		70	
	*	**	*	**	*	**	*	**
Airframe	8.6	40.0	23.3	30.5	29.7	24.3	32.0	24.7
Seats	0.0	0.0	19.7	0.7	19.7	0.5	19.7	0.5
Controls	9.0	38.4	14.3	17.3	40.7	30.6	45.8	32.5
Drive	0.0	0.0	4.8	1.6	36.0	7.6	36.0	7.1
Electrical	3.5	12.9	25.5	26.3	25.5	16.4	25.5	15.5
Fuel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydraulics	0.0	0.0	5.5	0.9	8.3	0.8	8.3	0.8
Instr. Instl	0.0	0.0	0.0	0.0	35.4	1.5	35.4	1.4
Oil Cooling	3.5	2.0	83.1	13.6	83.1	8.5	83.1	8.0
Power Plant	5.6	6.7	15.0	5.0	18.3	3.8	18.3	3.6
Rotors	0.0	0.0	0.5	0.2	2.8	0.6	2.8	0.5
Caution/Warn	0.0	0.0	4.1	1.0	25.1	3.6	25.1	3.4
Aux. Equip.	0.0	0.0	30.5	2.9	30.5	1.8	35.3	2.0
Aircraft Totals	5.3	100.0	18.7	100.0	30.0	100.0	31.8	100.0

*Percentage Decrease in Subsystem Failure Rate
**Percentage Contribution Total Decrease in Failure Rate

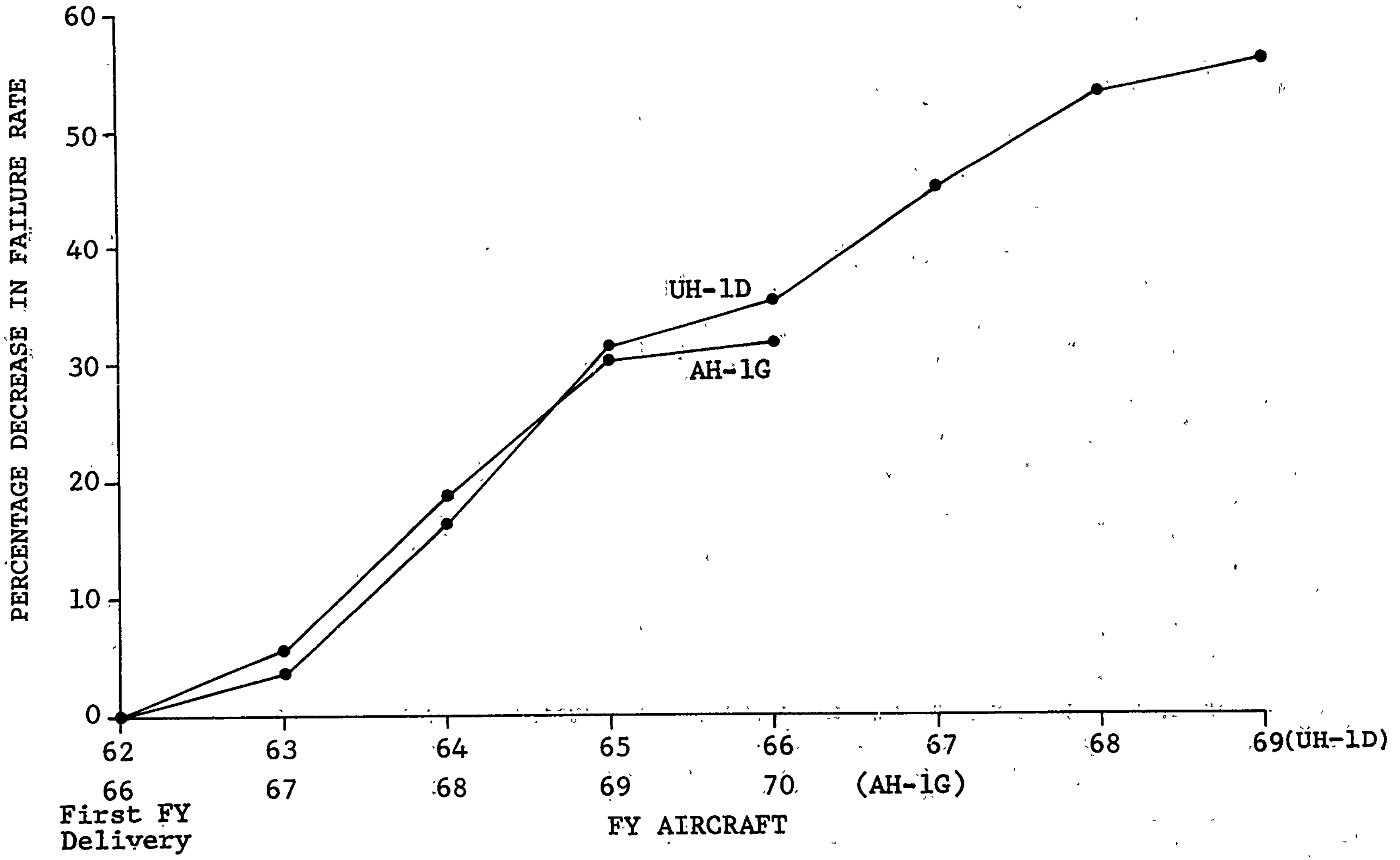

Figure 34. Percentage decrease in failure rate versus FY aircraft.

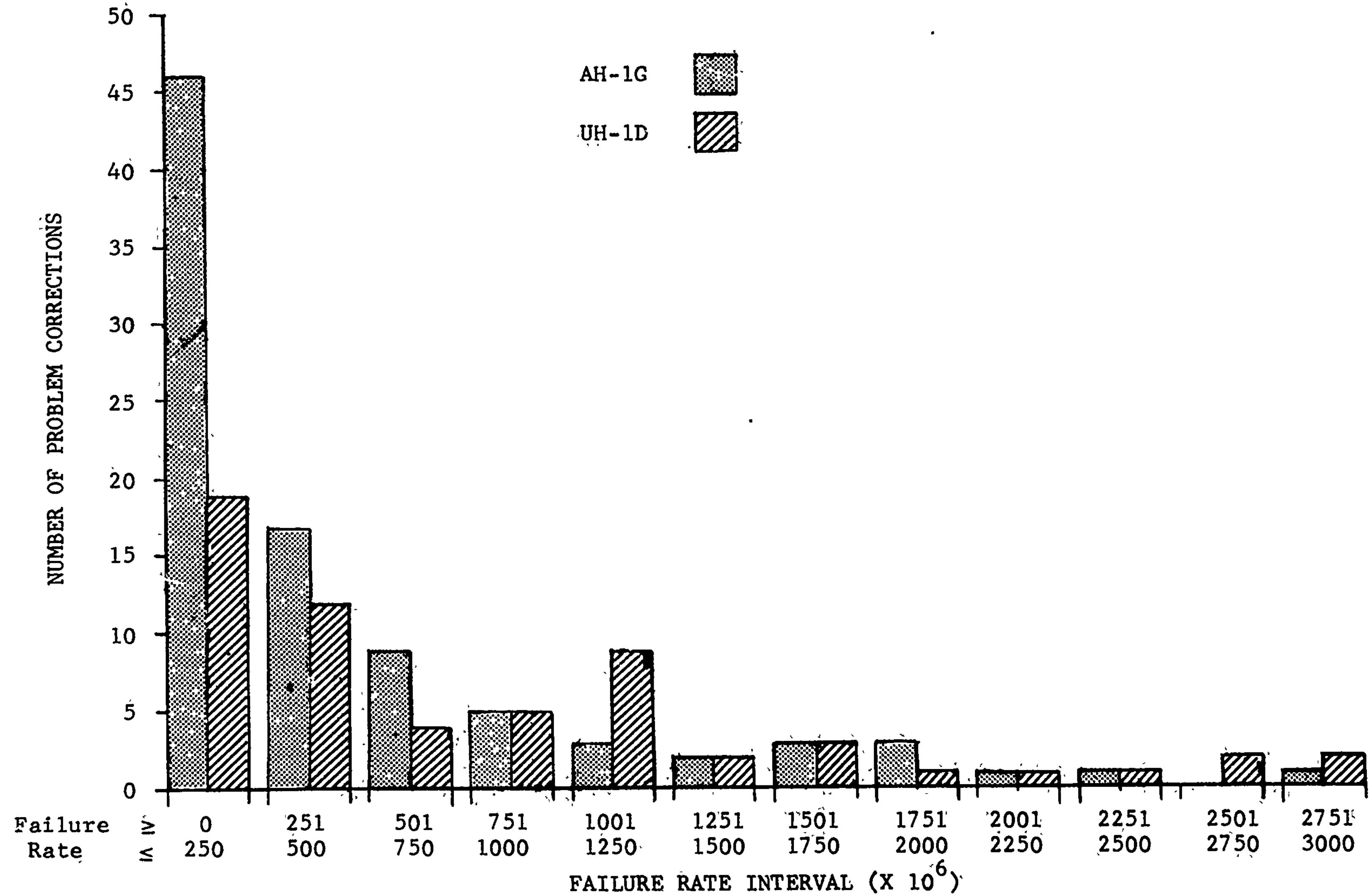

Figure 35. Number of problem corrections versus magnitude of the failure rate.

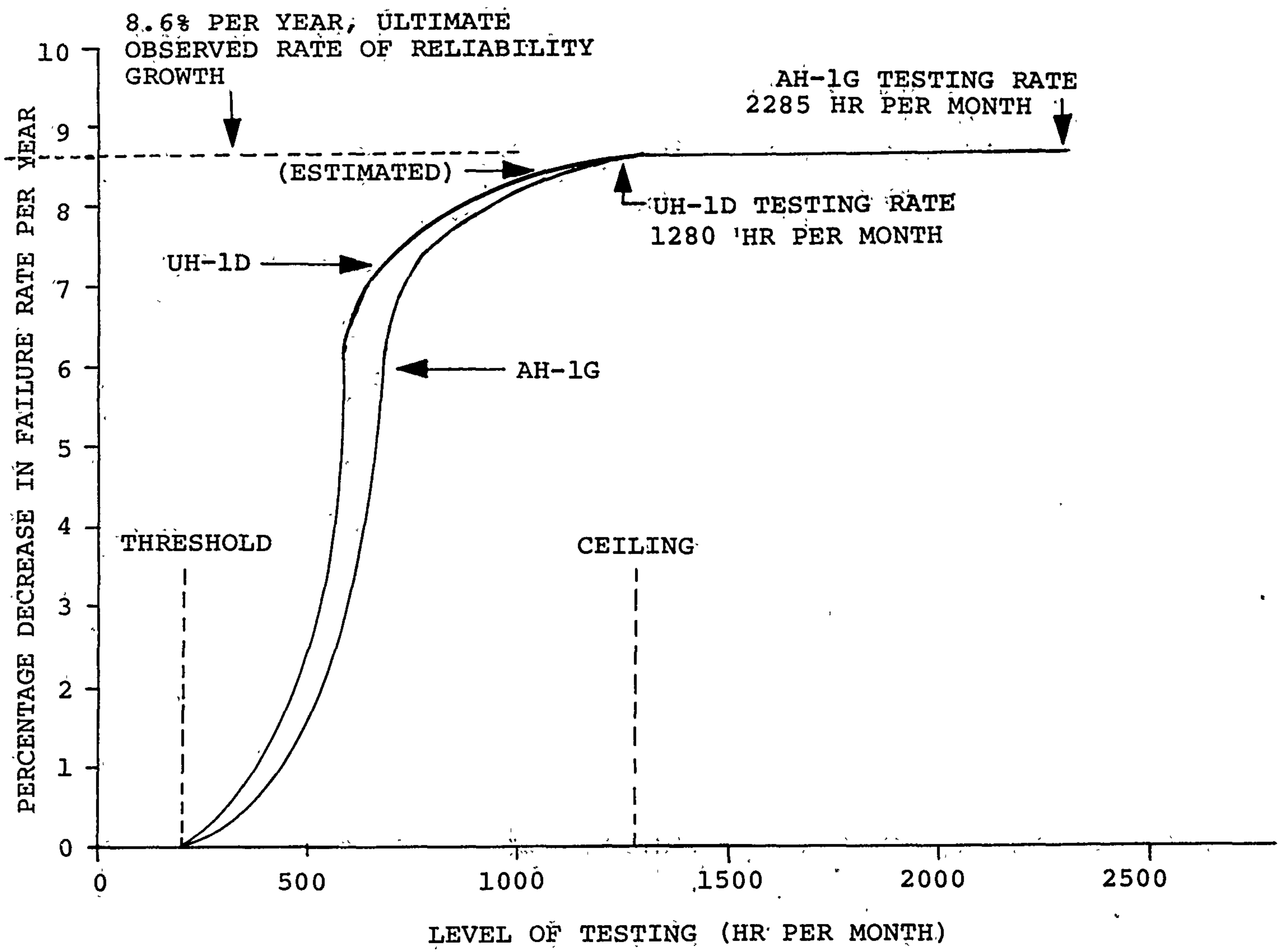

Figure 36. UH-1D and AH-1G reliability growth rate versus level of testing.

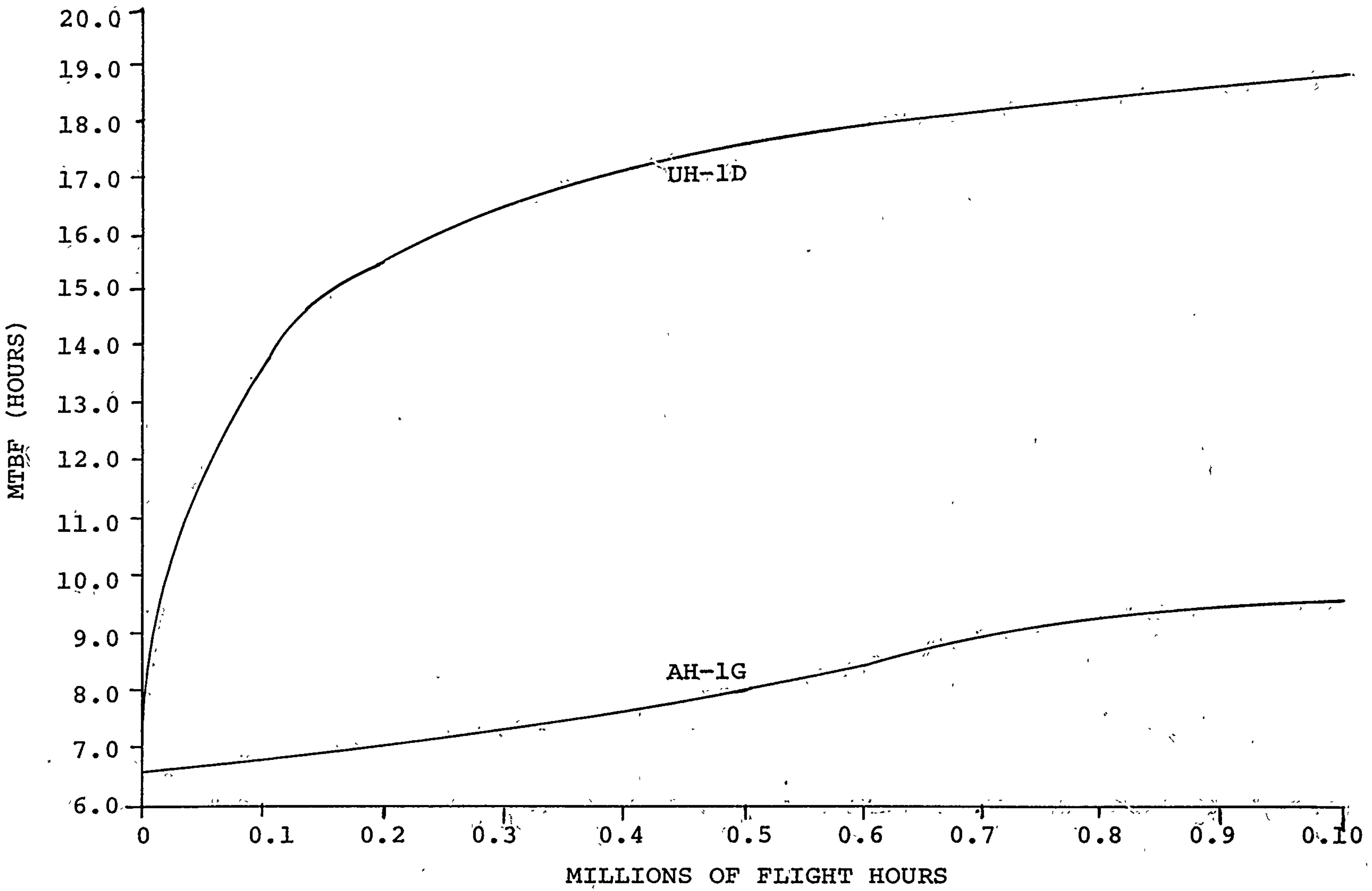

Figure 37. Reliability growth MTBF versus flight time for the UH-1D and AH-1G.

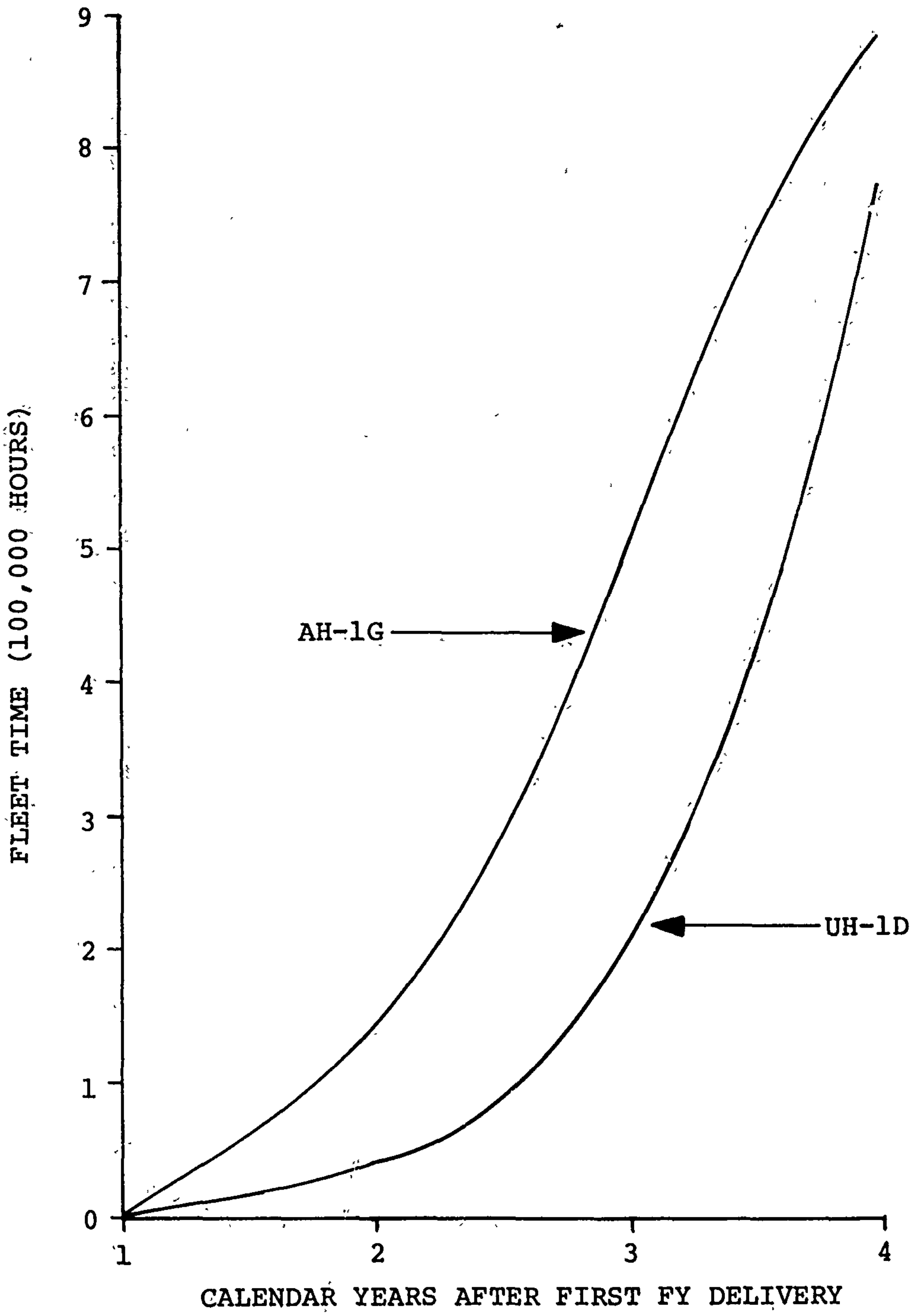

Figure 38. UH-1D and AH-1G fleet time accumulation versus calendar year after first FY delivery.

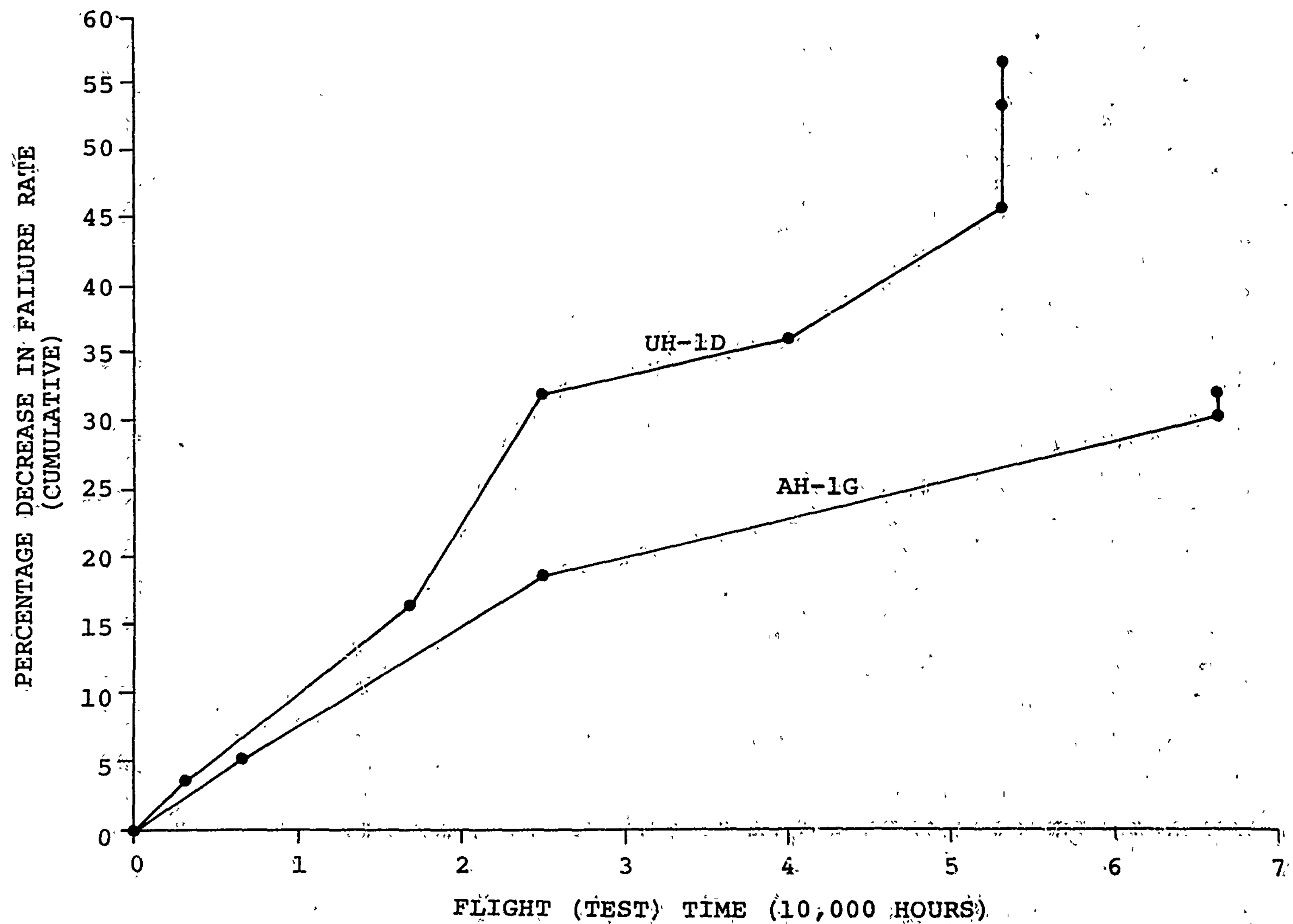

Figure 39. Reliability growth for the UH-1D and AH-1G. (Percentage decrease in failure rate versus operating time)

4.0 HELICOPTER RELIABILITY GROWTH PREDICTION TECHNIQUES FOR FUTURE HELICOPTER DEVELOPMENT

A limited helicopter reliability growth prediction technique has been developed from the relationships defined in this study. It has been demonstrated that under the conditions that existed in the UH-1/AH-1 M&R program, the rate of reliability growth was constant and equal for the UH-1D and AH-1G. This fact allows other relationships to be developed that permit the tailoring of test programs to budget, required MTBF, and off-board MTBF. There may be risk involved in applying this technique to helicopters not of the same size and complexity as the UH-1D and AH-1G and manufactured by someone other than BHC. The technique may be limited in that it is derived from data from a failure monitoring and corrective action activity on a sample fleet of 30 or more initial production aircraft with a test time accumulation rate in excess of 1200 flight hours per month. The 30 aircraft fleet is significant in that it was determined to be a statistically valid sample consistent with the M&R program definition of a problem requiring correction action. The 1200 flight hours per month ensures that a level of testing is maintained consistent with the growth rate demonstrated on the UH-1D and AH-1G. Obviously, the technique is not intended to be used to predict a rate of reliability growth, since that value is a constant. It is intended to be used to predict test time required to achieve a given mature MTBF, knowing beforehand the value of the off-board MTBF. It is to be used to predict what off-board MTBF is required to meet a given mature MTBF with a limited number of test hours. Also, it is to be used to determine what level of mature MTBF can be achieved with a known off-board MTBF and a limited number of test hours.

4.1 BASIS FOR DEVELOPMENT OF THE PREDICTION TECHNIQUE

It has been shown that the reliability growth rates of the UH-1D and AH-1G are equal when expressed as a cumulative percentage reduction in failure rate versus fiscal year aircraft model. The fiscal year aircraft model scale, for practical purposes, can be converted to calendar years, because each point on that scale marks the beginning of a fiscal year model delivery within a calendar year. Percentage reduction in failure rate and calendar years are the logical axes on which to plot reliability growth. This method has been shown to be insensitive to variations in program intensity, rate of test-hour accumulation (above some ceiling level of testing), total test hours, rate of problem correction initiation, and type of aircraft. It makes use of the one variable that appears to dominate all others, i.e., the length of time necessary to incorporate corrective action.

Section 3.3.3 demonstrated the linear relationship that exists between cumulative percentage reduction in failure rate and growth time. The UH-1D and AH-1G reliability growth curves both exhibited slopes of 8.6 percent per year reduction in failure rate based on the off-board failure rate. This relationship was shown to exist through 8 calendar years.

4.2 DEVELOPMENT OF THE PREDICTION TECHNIQUE

A mathematical relationship among off-board Mean-Time-Between-Failures ($MTBF_{OB}$), mature or required Mean-Time-Between-Failures ($MTBF_R$), and reliability growth time is easily established, knowing that the rate of reliability growth is a constant. Cumulative percentage reduction in failure rate is computed from an initial failure rate or off-board failure rate λ_{OB}, where

$$\lambda_{OB} = \frac{1}{MTBF_{OB}}$$

and from a mature failure rate or required failure rate λ_R, where

$$\lambda_R = \frac{1}{MTBF_R}$$

Since a cumulative percentage reduction in failure rate exists in a linear relationship with calendar years of reliability growth, an equation relating the two will be of the form

$$y = mx + b$$

where $m = 8.6$ slope of the line

$b = 0$ since the line will pass through the origin

$x = T_g$ calendar years of growth

and $y = \left(\frac{\lambda_{OB} - \lambda_R}{\lambda_{OB}}\right)(100)$ percent reduction in failure rate.

Substituting for y, m, and x,

$$\left(\frac{\lambda_{OB} - \lambda_R}{\lambda_{OB}}\right)\left(100\right) = 8.6\ T_g$$

Simplifying the equation and solving for T_g,

$$T_g = \left(1 - \frac{\lambda_R}{\lambda_{OB}}\right) \bigg/ .086$$

Substituting for λ_R and λ_{OB},

$$T_g = \left(1 - \frac{MTBF_{OB}}{MTBF_R}\right) \bigg/ .086 \qquad (8)$$

where $8 \geq T_g \geq 0$.

since this relationship is not known to be valid beyond 8 calendar years.

Recall from Section 3.3.3 that calendar years of reliability growth, T_g, could be related to calendar years of testing, T_t, through correlation with the Fibonnacci sequence, whose ratio of consecutive terms is $\frac{1 + \sqrt{5}}{2}$, or 1.618. Thus,

$$T_g = 1.618\ T_t$$

Substituting for T_g,

$$1.618\ T_t = \left(1 - \frac{MTBF_{OB}}{MTBF_R}\right) \bigg/ .086$$

$$T_t = \left(1 - \frac{MTBF_{OB}}{MTBF_R}\right) \bigg/ .139 \qquad (9)$$

where $4.94 \geq T_t \geq 0$.

This equation defines the relationship among calendar years of testing, off-board MTBF, and mature or required MTBF.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The data retrieval and analysis effort and the UH-1D and AH-1G reliability growth evaluations indicate that:

- Reliability growth of the UH-1D and AH-1G was constant.

- There are many variables that may affect reliability growth. However, the time required for incorporation of a corrective action dominates all other variables.

- The Reliability Planning and Management procedure is not valid for defining helicopter reliability growth.

- For helicopters, there exists a level of testing above which further increases in testing will not increase the rate of reliability growth.

- Intensive reliability engineering effort should be expended during the design phase of new helicopter development to ensure that the off-board MTBF is as high as possible. This will minimize the reliability monitoring program required to achieve the required mature MTBF.

- The investment in an aggressive reliability engineering effort during the design effort is the most cost-effective way to improve the helicopter. This does not imply that reliability growth testing and monitoring programs should be abandoned. There are mission- and environment-related failure modes that cannot be forecasted from drawings. Early discovery and timely correction failure modes via a reliability monitoring program on an early production lot of fielded aircraft coupled with an effective reliability engineering effort during the design phase will ensure the most timely and cost-effective achievement of the overall aircraft reliability goals.

5.2 RECOMMENDATIONS

As a result of the above conclusions, it is recommended that:

- A reliability program of field failure monitoring on a controlled sample of helicopters be made a part of each new helicopter develcpment.

- A study be conducted to determine the optimum and minimum rate of test-hour accumulation for reliability failure monitoring activities on helicopters.

- A helicopter reliability growth evaluation be conducted on helicopters manufactured by contractors other than Bell Helicopter Company. This will determine whether the findings in this study are typical of other helicopters and will determine the applicability to other helicopters of the reliability growth prediction technique formulated in this study.

- A study be conducted to examine what connection, if any, exists between the failure mode criticality of the corrected problems and the length of time required to correct those problems. It may be revealed that helicopter reliability growth is proportionate to failure mode criticality.

APPENDIX A

FACTORS LEADING TO TERMINATION OF THE OH-58A RELIABILITY GROWTH EVALUATION

The OH-58A portion of the study was discontinued when it was determined that the data sources available would not provide the required information to support a reliability growth evaluation. The OH-58A was not the subject of an M&R field program as were the UH-1D and AH-1G. There is no period in its history where a failure monitoring and problem corrective action program was conducted. There have been various test programs for the OH-58A. Table A-1 presents a test-hour summary. A 2400-hour reliability and maintainability demonstration was conducted using two FY 68 OH-58A helicopters to demonstrate that the OH-58A would meet its maintainability and reliability guarantees. Problem identification and corrective action initiation were incidental. Although several design changes were made as a result of the demonstration, that effort was not a development program. Had there been a monitoring program to track the OH-58A reliability growth following the 2400-hour demonstration, the FY 68 model would have provided a baseline configuration to which subsequent FY models would have been compared. This could not be accomplished. The most significant obstacle in tracking the growth of the OH-58A was the lack of credible data covering more than one fiscal year model aircraft. It was believed that BHC's Discrepancy/Malfunction Reporting System (failure reports from BHC Service representatives and helicopter users) would provide sufficient data on aircraft subsequent to FY 68 models to identify problems and compute failure mode rates. The data proved to be inadequate on all of the models subsequent to FY 68. This was due in part to Army termination of technical representative contracts. It was at this point that the decision was made to discontinue efforts on the OH-58A and to concentrate on the UH-1D and AH-1G helicopters.

TABLE A-1. TEST HOURS SUMMARY FOR OH-58A

Model	Test Type						Data Source	Begin. Date
	Demo or Evaluation	Ground Run	Tiedown	Flight Test	Bench Test	Shake-down		
OH-4A					461.9		20663M-64	11-62
OH-4A		379.7		542.6			206-099-011	12-62
OH-4A			163.9				206-194-007	9-63
OH-4A	1200						Log Eval.	1-64
OH-4A				50.1			206-194-016	4-64
206A				299.4		28.2	206-194-031	4-66
206A		103.1					206-194-027	7-66
206A					150		206-097-002	3-68
206A-1	100	100					206-194-065	12-68
OH-58A					545		206-097-003	7-68
OH-58A				220.1			206-194-084	5-69
OH-58A	2407						R&M Demo	6-69
OH-58A		140.8					206-194-102	11-70
TOTALS	3707	723.6	163.9	1112.2	1156.9	28.2	TOTAL	6891.8

APPENDIX B

A SUMMARY OF RESEARCHED MATERIAL NOT PRESENTED IN THE RELIABILITY GROWTH STUDY TEXT

A significant amount of material was researched in support of the helicopter reliability growth evaluation but was not presented in the text of this report. These research efforts identified and eliminated those lines of investigation that would not contribute to the study. It was known prior to the execution of this contract that there existed a probability that some of the data sources investigated might not provide useful information. This appendix presents a summary of those research efforts including their intended use and the reasons for failure.

DATA TYPE

BHC Flight Test and Ground Vehicle Test Records.

Data Description

These data consist of many types of records of activity at the BHC Flight Test Facility. Four types of records contain most of the information. The first, Flight Sheet (BHC Form 7868 55360, EXPERIMENTAL FLIGHT TEST RECORD), is filled out for each flight or ground run. The flight sheet contains the flight time, number of takeoffs and landings, total flight time, total engine time, purpose, pilot's remarks, aircraft cg and gross weight, and other information pertaining to the aircraft configuration. The flight sheet also contains a summary of maintenance and component changes since the previous flight. The second is the Flight Test Work Sheet (BHC Form 7878 55440). This form is used to record each maintenance action performed on the aircraft. The third and fourth types of records are the Flight Test Engineer's Report and the Flight Test Pilot's Report. These records are engineering reports which describe the purpose of the test, how it was conducted, and the results.

Intended Use in This Study

It was believed that these data could provide sufficient information such as aircraft time and component failures to establish an off-board MTBF for the aircraft models in this study.

Results

A review of these data revealed that even though each maintenance action was recorded, it was not indicated if the maintenance was required due to a failure or some type of nonfailure cause. A significant amount of maintenance data appears to be adjustments, inspections, and instrumentation.

The data were not in a format that could be readily computer processed. In order to be used for this study, prohibitively extensive research in the files of each aircraft would be required.

DATA TYPE

TAERS (The Army Equipment Record System)
TAMMS (The Army Maintenance Management System)

Data Description

The BHC file of TAERS/TAMMS data consists of 65 reels of magnetic tape containing approximately 12 million records received from AVSCOM. These records are DA Form 2407 (Maintenance Requests), DA Form 2408 (Equipment Reocrds), and DA Form 2410 (Component Removal and Repair/Overhaul Records) on UH-1, AH-1, and OH-58A aircraft. They contain records of maintenance actions performed on each of the types of aircraft in the study.

Intended Use in This Study

It was intended that the data be used to obtain MTBF and MTBR values for aircraft systems and components by aircraft production lot. Since the maintenance and failure data on the 2407/08 form is recorded by Federal Stock Number (FSN) and nomenclature, it must be sorted by FSN/part number, cross-referenced, and listed by part number before it is readily usable. Since these records do not contain a part or component time, it is necessary to sort the data by aircraft serial number and date or aircraft time to determine if the discrepant part has been installed since new or has been previously replaced. By subtracting the first reported aircraft time from the last reported time for each aircraft, an approximate time base can be established for a certain calendar period. With the above tasks accomplished, it would be possible to estimate a part MTBF, MTBR, and reliability for a specific aircraft production lot.

The 2410 records have both FSN and part number blocks and also have blocks for part serial number and time and aircraft serial number and time. However, these records are used only for "reportable items," i.e., those parts with an established Time Between Overhauls (TBO).

Results

The file of 2407/08 records was sorted, and those records containing an FSN were compared to a file of FSNs with corresponding part numbers. Listings by aircraft model for particular time periods were generated. A review of the listings revealed that a large quantity of the 2407/08 records contain no FSN. The nomenclature was not descriptive enough to determine the part number. Further, it was found that approximately one-half of those 2407/08 records with an FSN recorded had invalid FSNs, i.e., the FSN did not have a corresponding part number on the cross-reference file. An invalid FSN may be the result of a wrong entry on the original form, a missed keypunch, or part number or serial number entered in the FSN block. Many of the remaining records were incomplete or incorrect in other data entry blocks such as failure code, aircraft serial number, and aircraft time. Therefore, the data were not usable.

DATA TYPE

3-M (Naval Aviation Maintenance and Materiel Management) Maintenance Records

Data Description

The BHC file of 3-M Maintenance Records consists of 11 reels of magnetic tape containing approximately 3 million records received from the Navy. These records are taken from the Navy OPNAV Forms 4790 on UH-1E, UH-1D, UH-1L, TH-1L, TH-57A, HH-1K, UH-1N, AH-1G, AH-1J, and UH-1H aircraft. They contain records of maintenance actions performed on each type of aircraft listed above. Several working files of data sorted by type of aircraft and type of data exist. Computer programs process these working files to provide listings by type of aircraft, containing maintnenace action rates, failure rates, abort rates, and maintenance man-hour data. These rates and maintenance man-hour data are broken down by work unit code (WUC).

Intended Use in This Study

It was intended that the data be used to obtain MTBF and MTBR values for aircraft systems and components by aircraft production lot.

Result

Extensive computer programming would have been required to obtain the data listings in a useful format. Further, a review of the raw data revealed that many records are incomplete or incorrect in the part number and part time data blocks, thus making the entire record useless.

DATA TYPE

3-M (Naval Aviation Maintenance and Materiel Management) Analysis Data

Data Description

These data are provided to BHC by the Navy and are contained on microfilm and computer tab runs and are in three different formats. The first, "Fleet Weapons Reliability and Maintainability Summary" (MSO 4790.A2142-01), covers data on Bell helicopters for the period from January 1967 through June 1973. This report is a six-month summary of the number of maintenance actions and failures and the corresponding rates for each work unit code. It also contains flight time, total maintenance man-hours, maintenance man-hours per flight hour, and elapsed time per maintenance action.

The second, "Aviation High NOR/RMC Items" (4790.A2099-01), data covers Bell aircraft from March 1972 through July 1973. These data are presented for each aircraft by command and by Navy total, NOR and RMC time for scheduled and unscheduled maintenance, and NOR/RMC due to supply for the three high items of system and the total aircraft.

The third, "Fleet Failure Summary" (4790.A2107-01), a report covering the most recent twelve-month period, is issued monthly. The data cover September 1971 through July 1973. This analysis lists the number of maintenance actions performed on each WUC.

Intended Use in This Study

The data were reviewed to determine if it was possible to extract aircraft serial number, total time, part failures, and part times.

Results

These data are a summary by aircraft type and WUC. They cannot be used to establish a correlation between aircraft production lot and part MTBF. Therefore, the data were of no value to the study.

DATA TYPE

Bell Helicopter Bench Test Records

Data Description

Engineering bench test reports and log books contain the results of bench testing. The following information is contained in the records:

- Nomenclature of componenet undergoing test
- Part number
- Test conditions (stress level, etc.)
- Duration of test
- Success or failure statement
- Failure mode if a failure occurs
- Occasionally, recommendations

Intended Use in This Study

It was believed that the tests could provide sufficient data to establish early component service life. The identification of failure modes present in the test was to be used to establish the configuration changes occurring in hardware prior to production. From this information, component reliability growth during the development stage could be determined.

Results

Many of the components being tested were never intended to be flight-quality hardware. Often, the tests being conducted subjected the component to stresses that do not compare with those encountered in normal service. Many were tests to destruction. Often, the records contained insufficient information to be useful to the program.

DATA TYPE

Design Change Documents

Data Description

The Product Change Authorization (PCA) is the document at Bell Helicopter Company which governs design changes. It is created following approval of an Engineering Change Proposal (ECP). The PCA is an administrative document whereas the ECP is a technical document.

Intended Use in This Study

Each PCA and ECP applicable to the helicopters in this study was to be examined to determine its impact, if any, on reliability growth. Those that did result in a reliability improvement were to be used to establish the configuration changes that resulted in an MTBF unique to each FY model.

Results

It was found that the volume of PCA's and ECP's was too great for the project manpower and budget. Design changes are initiated for a variety of reasons including advancement in state of the art, safety, customer request, specification violations, cost reduction, product improvement, and reliability improvement. Determining whether a PCA resulted in improved reliability or not required lengthy data search and analysis. It was determined that the practical way to approach the problem was to search for corrected problems and to key those back to the individual ECP's and PCA's to determine effectivities. The configuration changes that resulted in reliability improvements could then be established.

DATA TYPE

D/MR (Discrepancy/Malfunction Report) for the OH-58A

Data Description

The D/MR (BHC Form 7871 57985) is used by BHC Service representatives and customers to report problems/failures and to request warranty consideration. The D/MR form is blocked for keypunch and contains aircraft time and part time, serial numbers, part number, and a description of the failure, a known or suspected cause, and action taken. This information is computer processed and listed by aircraft model.

Intended Use in This Study

Since there was no M&R field program performed on the OH-58A, a cursory analysis of the D/MR data was conducted to determine if it was suitable for use in this growth study.

The D/MR data for FY 68, FY 69 and FY 70 OH-58A aircraft was reduced, and summary sheets were prepared containing failed parts information used to calculate and plot MTBF versus calendar time.

Results

It was determined from the above data review that the D/MR file did not adequately cover any configuration beyond the first OH-58A FY 68 configuration; therefore, no reliability growth could be shown.

DATA TYPE

Component Overhaul Data

Data Description

BHC Reliability Engineering Group has files of Major Component Overhaul Data from overhauls at BHC and ARADMAC. The ARADMAC data, supplied on listings from the Army, are keypunched and added to the BHC files. The data are stored on two magnetic tape files (five reels) except for 12 file drawers of completed OSM 634 forms. One file, W6400, contains removal data including aircraft serial number, part number, time, component serial number, and other information related to the removal for overhaul. The second file, Z500, contains a record of each part replaced during overhaul on a major componenet in the W6400 file, including the reason for replacement.

Intended Use in This Study

These data were reviewed to determine if they could be used for configuration traceability of major components used on the aircraft models involved in this study. Other possible uses included component failure identification, component time, and aircraft time.

Results

It was determined from the review that the data are accurate enough and complete enough to be used as intended; however, because the data are applicable to only a relatively few components per aircraft, and because the large volume of data is not readily researched, they were not used.

APPENDIX C

APPLICATION OF THE RELIABILITY GROWTH PREDICTION TECHNIQUE TO A HYPOTHETICAL HELICOPTER

The reliability growth prediction technique developed in Section 4.0 of this study has been applied to a hypothetical helicopter. Three different situations will be presented to illustrate the use of the prediction technique. The following will be common to the first two situations. A new helicopter has been designed and fabricated. Several prototype aircraft have been flight tested and initial production deliveries will begin soon. A reliability and maintainability monitoring program will use the first 30 helicopters available. The 30 helicopters will fly an average of 40 flight hours or more per month. The data from these sample aircraft will be used in a concerted, organized effort of problem identification and corrective action.

Situation #1. Through flight test of the prototype aircraft and predictions based on design changes to be incorporated on the production aircraft, the off-board MTBF has been determined to be 5.5 hours. The minimum acceptable MTBF is 8.4 hours. How much reliability testing will be required to achieve the minimum acceptable MTBF?

Given:

$$T_t = \left(1 - \frac{MTBF_{OB}}{MTBF_R}\right) \Big/ .139$$

$$MTBF_{OB} = 5.5$$

$$MTBF_R = 8.4$$

Find T_t:

$$T_t = \left(1 - \frac{5.5\ hr}{8.4\ hr}\right) \Big/ .139$$

$$T_t = 2.5 \text{ calendar years}$$

Test hour accumulation on the monitored fleet, T_{HR}, will be

$$T_{HR} = (2.5 \text{ calendar yrs}) \times 12 \text{ mo/calendar yr} \times \frac{1200\ hr}{mo}$$

$$T_{HR} = 36{,}000 \text{ flight hours}$$

Situation #2. Through flight test of the prototype aircraft and through predictions based on design changes to be incorporated on the production aircraft, the off-board MTBF has been determined to be 9.0 hours. Funds have been allocated for a 2-1/2-year M&R program. What will be the MTBF achieved with 2-1/2 years of testing?

Given:

$$T_t = \left(1 - \frac{MTBF_{OB}}{MTBF_R}\right) \Big/ .139$$

$$T_t = \text{2-1/2 years}$$

$$MTBF_{OB} = 9.0$$

Find $MTBF_R$:

$$MTBF_R = \frac{MTBF_{OB}}{1 - .139\ T_t}$$

$$MTBF_R = \frac{9.0}{1 - .139(2.5)}$$

$$MTBF_R = 13.8 \text{ hr}$$

Situation #3. A new helicopter is being designed. The mature MTBF requirement is 10.0 hours. There will be a reliability monitoring program funded for 4 calendar years beginning with production deliveries. What is the minimum off-board MTBF that must be achieved from the design effort and prototype testing to meet the mature MTBF requirement in 4 calendar years of testing?

Given:

$$T_t = \left(1 - \frac{MTBF_{OB}}{MTBF_R}\right) \Big/ .139$$

$$MTBF_R = 10.0$$

$$T_t = 4.0$$

Find $MTBF_{OB}$:

$$MTBF_{OB} = (MTBF_R)(1 - .139\ T_t)$$

$$MTBF_{OB} = (10)(1 - .139(4))$$

$$MTBF_{OB} = 4.4 \text{ hr}$$

How many calendar years of growth does this represent?

Given: $T_g = 1.618\ T_t$

$T_t = 4$

Find: T_g

$T_g = 1.618(4)$

$T_g = 6.5$ years

GLOSSARY

1. Baseline Failure Rate (λ_b) is the sum of the failure rates of parts that are common to a group of similar items, e.g., components common to different fiscal year production blocks of aircraft of the same model.

2. Component is a basic assembly or part which performs a function.

3. Failure is the inability of a component or system to satisfy performance or design specifications, given that the equipment has previously experienced successful operation or acceptance or has the expectation of successful performance without adjustment, rework, or replacement. Maintenance actions resulting from assembly error by the manufacturer are considered failures. Maintenance actions resulting from unsatisfactory part conditions that are not caused by (1) maintenance or operating personnel, (2) objects external to the aircraft, or (3) failures of components in another helicopter subsystem are considered failures.

4. Failure Rate (λ) is the number of failures per unit time,

$$\lambda = \frac{\text{Failures}}{\text{Flight Hours}}$$

assuming that failure distribution of time to failure is exponential,

5. Helicopter System is the helicopter, consisting of all its systems.

6. Mean-Time-Between-Failures (MTBF) is the average operational flight time in hours (for fleet or sample) between failures. It is determined by dividing the total observed or monitored flight time by the number of failures observed during that flight time.

$$\text{MTBF} = \frac{\text{Flight Hours}}{\text{Failures}}$$

7. Observed Reliability is the reliability of the sample of aircraft calculated using the number of failures observed and flight hours accrued during a defined elapsed calendar time.

8. Off-board MTBF is the MTBF of a design that has been successfully translated into flight-quality hardware. For helicopters, the first flight is the time that the design is considered off-board.

9. Production Effectivity is the identification, by first delivered aircraft tail number for the fiscal year of production, of the production incorporation of design changes.

10. Reliability Growth is the increase in reliability with time.

11. Subsystem is an installation or assembly of one or more components which performs a function within a helicopter system.

12. System Reliability is the probability that the end item (helicopter) will fly for a specified time without incurring a failure in any subsystem or component which would require unscheduled maintenance.

13. α. If reliability growth can be shown as a straight line or lines on log-log paper, then α is the slope.

$$\alpha = \frac{\log_e(y_1/y)}{\log_e(x_1/x)}$$

, where (x,y) and (x_1, y_1) are two points on a line with a slope of α.